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Securing Containerized Hazardous Wastes with Welded Polyethylene Encapsulates

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SECURING CONTAINERIZED HAZARDOUS WASTES WITH WELDED POLYETHYLENE ENCAPSULATES

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16. ABSTRACT

Full-scale encapsulation of 208-liter (55-gal) drums was studied as a means for managing corroding containers of hazardous wastes in the field and rendering them suitable for transport and safe deposit within a final disposal site such as a landfill. Polyethylene (PE) receivers with 6.35-mm- (¼-in.-) thick walls and wide mouths were employed for fabricating encapsulates. After insertion of drums, the receivers were weld-sealed with 6.35-mm (¼-in.) sheet PE. A prototype apparatus was designed and constructed to fabricate the PE encapsulates by welding. The apparatus, which was light weight and transportable, was analogous to that employed in the commercial butt welding of PE pipe. Precision alignment of pieces and high regularity of surfaces to be joined were found to be unnecessary. Furthermore, only minimal mechanical pressures were needed to form the welded joints. Results indicated plastics welding to be an effective method for encapsulating corroding drums of hazardous wastes.

This report is a companion to two other documents investigating the use of plastics for the encapsulation of corroding containers of hazardous wastes: Securing Containerized Hazardous Wastes with Polyethylene and Fiberglass Encapsulates (EPA-600/) and Securing Containerized Hazardous Wastes by Encapsulation with Spray-on/Brush-on Resins (EPA-600/).

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governent concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report discusses a method for encapsulating leaking drums of hazardous wastes with welded polyethylene to form seamless containers suitable for safe transport and long-term disposal.

Francis T. Mayo, Director
Municipal Environmental Research
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ABSTRACT

Full-scale encapsulation of 208-liter (55-gal) drums was studied as a means for managing corroding containers of hazardous wastes in the field and rendering them suitable for transport and safe deposit within a final disposal site such as a landfill. Corroding containers of hazardous wastes reside throughout the American Landscape. They constitute a hazard to man and his environment. Clearing these locations involves transporting the wastes, an operation that requires waste ensembles that conform to Department of Transportation (DOT) regulations governing transportation of containerized hazardous wastes. Should the waste be disposed of in a final disposal site, the containers must be constituted to resist degradation by the physical and chemical stresses of the disposal environment.

Polyethylene (PE) receivers with 6.35-mm-(1/4-in.-) thick walls and wide mouths were employed for fabricating encapsulates. After insertion of drums, the receivers were weld-sealed with 6.35-mm (1/4-in.) sheet PE.

A prototype apparatus was designed and constructed to fabricate the PE encapsulates by welding. The apparatus, which was light weight and transportable, was analogous to that employed in the commercial butt welding of PE pipe. Precision alignment of pieces and high regularity of surfaces to be joined were found to be unnecessary. Furthermore, only minimal mechanical pressures were needed to form the welded joints.

Results indicated plastics welding to be an effective method for encapsulating corroding drums of hazardous wastes. Strong, watertight joints were formed between PE receivers and PE sheet. Since receivers and sheet are available from commercial sources, the encapsulation process can be carried out as a full-scale operation. The welded PE encapsulate performs a unique service because wide-mouth PE containers that comply with DOT specifications are not commercially available for 208-liter (55-gal) drums.

This report is a companion to two other documents investigating the use of plastics for the encapsulation of corroding containers of hazardous wastes: Securing Containerized Hazardous Wastes with Polyethylene and Fiberglass Encapsulates (EPA-600/2-) and Securing Containerized Hazardous Wastes by Encapsulation with Spray-on/Brush-on Resins (EPA-600/2-).

This report was submitted in fulfillment of Contract No. 68-03-2483 by TRW Defense and Space Systems Group and Contract No. 68-03-2993 by Environmental Protection Polymers, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period 1978 to 1980, and work was completed as of December 1980.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

AC	--alternating current	gpm	--gallons per minute
gal	--gallon	UHMWHDPE	--ultra-high-molecular-weight, high-density polyethylene
ml	--milliliter		
in.	--inch	MPa	--megapascal
ft	--foot	kPa	--kilopascal
ft^3	--cubic foot	psi	--pounds per square inch
ft^2	--square foot	psig	--pounds per square inch gauge
m	--meter	^oF	--degrees Fahrenheit
cm	--centimeter	^oC	--degrees Celsius
mm	--millimeter	^oK	--degrees Kelvin
μ	--micron	Btu	--British thermal unit
$in.^2$	--square inch	Cal	--calories
m^2	--square meter	kW	--kilowatts
cm^2	--square centimeter	hp	--horsepower
mm^2	--square millimeter	V	--volts
$in.^3$	--cubic inch	AMP	--amperage
m^3	--cubic meters	HZ	--Hertz
cm^3	--cubic centimeter	Al	--aluminum
mm^3	--cubic millimeter	Vol	--volume
lb	--pound	OD	--outside diameter
kg	--kilogram	ID	--inside diameter
g	--gram	ht	--Height
lb-mole	--pound mole	DOT	--Department of Transportation
ppm	--parts per million	ASTM	--American Society for Testing and Materials
lb/ft^3	--pounds per cubic foot		
g/cm^3	--grams per cubic centimeter	PE	--polyethylene
min	--minute	HDPE	--high-density polyethylene
sec	--second	MDPE	--medium-density polyethylene
hr	--hour		

SYMBOLS

--pump

--alternating current source

--control valve

--valve

--spool valve

--4-way valve

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The authors also extend their thanks to Mrs. V. R. Butler for providing clerical services. Her constant cooperation is greatly appreciated.

SECTION 1

INTRODUCTION

This work is a continuation of earlier work carried out at TRW for the U.S. Environmental Protection Agency to develop encapsulates to secure corroding, 208-liter (55-gal) steel drums holding hazardous wastes. The object of this study was to provide another option for encapsulating drums in addition to the one developed previously.[1] The establishment of two viable options broadened the base for studying the feasibility of a commercial operation.

The process options were restricted to those that would produce seam-free containers for use as encapsulates. This approach distinguished the work from current developments in container technology and, in our opinion, yielded encapsulates with advanced performance qualities. The costs for seamed and unseamed containers were estimated to be comparable. The similar costs were plausible because the resins employed were mass produced and of the same type as those employed in commercial containers; furthermore, the encapsulate fabrication apparatus was simple enough to counterbalance production advantages associated with expensive commercial apparatuses.

Earlier work had developed laboratory-scale encapsulates characterized by 6.35 mm (1/4-in.) polyethylene (PE) outer walls reinforced by fiberglass casings. The encapsulates' features were their homogeneous, seam-free outer walls and their high compressive strengths. Encapsulates of drums, therefore, would not be encumbered by ancillary closure devices associated with conventional containers such as lids, threads, gaskets, hoops, etc.

In this study, the container walls were not reinforced. The resulting encapsulates, although seam-free, exhibited less mechanical strength than the fiberglass-reinforced models, but they were expected to be sufficiently strong for securing drums. (Additional strength, if required, was obtainable by placing filler material such as foam in the free space between the walls of inserted drums and those of the containers.)

Use of unreinforced polyethylene containers permitted greater utilization of commercially available materials and techniques, and it allowed a more direct application of current technology to securing 208-liter (55-gal) drums in the field. Such advantages were considered to counterbalance the probable losses of mechanical performance.

Though commercial plastic containers were not available for securing

208-liter (55-gal) steel drums, the rotomolding industry did fabricate PE receivers large enough to accommodate these drums. Such receivers were successfully employed as freestanding tanks for holding corrosive chemicals and for carrying out chemical reactions. The PE resins used in their fabrication were mass produced and were well characterized by their producers. Rotomolded PE receivers were, according to our estimate, the commercially available materials best suited for securing drums. Extruded PE flat stock was selected for sealing the receivers.

Plastic welding was the commercial technique selected for sealing the receivers. Welding is a widely used, high performance technique for joining materials, both metals and plastics. Its structural and sealant performance characteristics are well known, and its wide acceptance attests to its merit. In the field of plastics, welding has been used successfully to join PE pipe, and commercial apparatuses are available for this purpose. Unfortunately, the equipment was not suitable for fabrication of PE encapsulates. To utilize the proven advantages that PE welding offers in the making of encapsulates, a novel plastic welding apparatus was designed and built to seal PE covers to PE receivers.

This report presents the results of an investigation to carry out full-scale encapsulation of 208-liter (55-gal) steel drums with welded polyethylene (PE). Materials are described along with the design and construction of the encapsulate welding apparatus, the technique employed for encapsulate fabrication, and an evaluation of encapsulates. A preliminary economic analysis of the encapsulation process is also presented.

SECTION 2

CONCLUSIONS

Full-scale encapsulation of 208-liter (55-gal) drums can be carried out by inserting drums into wide-mouth polyethylene (PE) receivers with 6.35-mm-(1/4-in.-) thick walls and sealing them by welding with PE flat sheet 6.35-mm-(1/4-in.-) thick. Characterizations of the welded joints indicate that the encapsulates would exhibit satisfactory performances (that is, they would comply with Department of Transportation (DOT) regulations concerning the transport of containerized hazardous wastes and their long-term, safe deposit in a landfill).

The apparatus designed and employed in this work for making prototype encapsulates was simple compared with commercial plastics fabricating devices, and it was also readily transportable. An apparatus for use in the field need not be more complex than the one employed here for making encapsulates. Improvements such as semiautomating can be accomplished at moderate costs.

Important features of the apparatus were its use of a flat ring heater and PE flat stock. These items allowed sealing of PE receivers with flat stock without the need for precise alignment. Furthermore, the surfaces to be joined did not need to be smooth. These features were expected to facilitate management of drums.

Compatibility of PE encapsulates and their contents can be determined from data supplied by vendors of PE resin. Extensive material compatibility data are available for PE, a fact that contributes greatly to the usefulness of this material in waste management. These data should be examined when selecting drums for encapsulation. The presence of deleterious materials remaining with corroding drums after long-term exposure to the atmosphere, however, would probably be an unlikely event.

The cost of the encapsulation process was mainly attributable to the cost of receivers and flat stock. Equipment and labor costs were negligible. Cost reductions will thus depend on making less expensive receivers and flat stock. duPont has indicated that it will receive unusable 208-liter (55-gal) drums, pulverize them, and sell the powder for about one-third the price of commercial PE. This material in turn would be usable for making receivers. Flat stock used for making ice skating rinks (a popular, energy-saving alternative to conventionally maintained ice) must be replaced periodically because of scarring, but it is still usable for weld-sealing receivers.

SECTION 3

RECOMMENDATIONS

More intensive investigation of the formation and nature of the welded joint between PE receivers and PE sheet stock should be carried out. This investigation should follow the guidelines presented in the art of PE pipe butt welding. The applied stresses would be appreciably less severe on the encapsulate joints than the pipe joints, thereby lessening the performance requirements of serviceable joints. This advantage was due mainly to the absence of dynamic and cyclical mechanical stresses on encapsulates.

In addition to determining how to produce high-performance welded joints, means should be examined for maximizing the welding apparatus performance in the field. Various equipment and labor scenarios should be examined for making drum-populated areas safe at a reasonable cost.

SECTION 4

MATERIALS AND EQUIPMENT

This section sets forth materials and equipment employed to encapsulate 208-liter (55-gal) drums. Particular emphasis was placed on using PE receivers fabricated by commercial rotomolding. Equipment was designed and constructed to seal the receivers with PE flat stock by plastics welding. PE pipe welding art was applied to determining equipment requirements and selecting processing conditions.

MATERIALS

Polyolefins, particularly PE (but not excluding high-impact polypropylene and polybutylene), were selected for fabricating encapsulates because such materials were well characterized, mass-produced, low in cost, and provided a unique combination of properties: excellent chemical stability, flexibility and mechanical toughness. Prior laboratory studies showed PE encapsulates to have high performance heavy metal contaminant retention when subjected to aggressive leaching solutions.[2]

Commercial PE containers were not available in size and in construction for encapsulating 208-liter (55-gal) metal drums. The largest plastic vessels that may be transported in compliance with DOT regulations were 208-liter (55-gal) drums fitted with bung holes. Wide-mouth drums did not qualify. Other PE vessels were not fitted with the means to effect secure closure. They were employed mainly as liners of steel and fiberglass-reinforced vessels, or as free-standing receivers and holding tanks. Their value was particularly noteworthy in process and storage operations involving corrosive chemicals. There was great interest by plastics fabricators to make, by rotomolding, large, free-standing PE tanks to replace plastic-coated or glass-lined steel tanks, stainless steel tanks, and fiberglass-reinforced plastic tanks. These PE tanks were selected as receivers of 208-liter (55-gal) drums.

To determine the size of receivers required for encapsulating 208-liter (55-gal) steel drums, dimensional descriptions of the standard drums were obtained by contacting several manufacturers. The standard drum was 60.6 cm (23 27/32 in.) in diameter and the longest height was 60.2 cm (23 11/16 in.). It was decided to add 1.27 cm (0.5 in.) to each dimension, plus 1 in. for clearance between the outside of the metal drum and the inside of the PE encapsulate. Consequently, the encapsulates were 66.9 cm (26 11/32 in.) in diameter and 94.5 cm (37 3/16 in.) long with 321-liter (85-gal) capacity.

Several procedures were surveyed to determine the most expedient one to position 208-liter (55-gal) drums for encapsulation. The survey suggested

insertion of the corroding 208-liter (55-gal) drums into prefabricated open-ended receivers and then welding covers onto them to be the best procedure. (In a commercial operation for stabilizing 208-liter [55-gal] drums, the drums were inserted into steel receivers and lids mechanically fixed them [see Appendix A].) Furthermore, wide-mouth PE receivers and PE flat stock for use as covers were commercially available in sizes and thicknesses 4.76 to 6.35 mm (3/16 to 1/4 in.) suitable to manage 208-liter (55-gal) drums. Another approach considered to be potentially useful involved inserting 208-liter (55-gal) drums into segments of PE pipe and welding PE covers onto the ends. Although extruded PE pipe of appropriate inside diameter was commercially available, they were found to be costly materials. Pipe segments, therefore, were appreciably more expensive than rotomolded receivers. As a result, this approach was not employed.

After commercial container art and the mechanics of encapsulate fabrication were considered, rotomolded, wide-mouth PE receivers and PE flat sheet were selected for making encapsulates. Though on-the-shelf receivers were longer than desired, they were capable of being readily constructed to specifications when needed in significant numbers (Appendix B). The specifications of materials employed for initial encapsulate fabrication were:

Receptacles
- --Rotomolded
- --6.35-mm-(1/4-in.-) thick walls
- --OD of 66.9 cm (26 11/32 in.) and height of 94.5 cm (37 3/16 in.)
- --Approximate weight of 20.5 kg (45 lb) (including cover)
- --Capacity of 321 liters (85 gal)
- --Resin: Rotothene MDPE R-8405-U (Rototron Corp.)

Covers
- --Cut from extruded flat stock
- --6.35-mm (1/4-in.) thick
- --Resin: Baltaron HDPE 5200 (General Tire)

The height and diameter of receptacles readily accommodated the 208-liter (55-gal) drums, as shown in Figure 1. The free space between receptacle and inserted drum can be filled, if required, with low-cost filler materials such as foam to minimize drum movement during handling. Furthermore, the free space allows encapsulation of distorted drums.

EQUIPMENT

Plastic welding was widely used for fusing segments of PE pipe end-to-end.[3] PE pipe with diameters from one to forty-eight inches were successfully welded in field operations. Commercially available butt welding equipment was used to effect watertight seals between the pipe sections.[4] However, this equipment was found to be unsuitable for PE encapsulate fabrication because the pipe welding equipment was designed to join pipe positioned horizontally and it was not applicable to vertically positioned pieces.

To fabricate PE encapsulates, a new plastic welding apparatus was designed and built. This apparatus was capable of welding flat PE covers onto the rim of wide-mouth receivers. The welding apparatus for encapsulate

fabrication was viewed as a container heat-sealing device comparable to commercially employed PE pipe welding devices. This encapsulation apparatus was designed as a prototype, experimental device which allowed altering various parameters affecting the properties of the welded joint (i.e., heating and cooling times, temperature, welding pressure, etc.). As with commercially employed pipe welding apparatuses, the prototype apparatus was designed to be easily transported and sturdy so that it could be used in field encapsulations of drums.

Though pipe fusion equipment could not be used to fabricate encapsulates, many requirements were similar. Consequently, pipe fusion equipment was studied to determine which components of the commercial equipment were applicable to fabricating welded plastic encapsulates.* Particular attention was given to the following components:

a) frame and clamps holding pipe
b) hydraulic system electrically driven
c) facer
d) heater
e) carriage holding the unit
f) pipe lifts

The carriage, facer, clamps, and pipe lifts which position the plastic welding apparatus for pipe welding were found not to be required for encapsulation.

A flat-plate metal heater and an electrically driven hydraulic system were used to heat and pressurize the PE pipe in the commercial pipe welding unit. These components were found to be applicable to encapsulation and especially well suited for fusing wide-diameter plastic pieces. Other heating techniques were considered, such as hot air or friction heating. But they would require complicated tooling because of the wide diameters of PE receivers. Consequently, a flat heater inserted between the plastic pieces was viewed to be one of the most simple heating arrangements for melting wide-diameter pieces. After the heater melted the PE pipe ends, it was removed so the ends could be joined together. The hydraulic system was capable of both parting the pipe so that the heater could be removed and then pressing the ends together. Furthermore, fusion pressure was easily adjusted. These features were found to be applicable to encapsulate fabrication, which, like pipe fusion, involves heating wide diameter rims of plastic. Thus the flat plate heater and hydraulic system were incorporated in the prototype apparatus for drum encapsulation.

With pipe welding as a guideline , a prototype apparatus was designed and constructed. Custom-made and commercially available components were employed. The apparatus had three major components: 1) the frame, 2) the hydraulic system, and 3) the heater. Of the three major components, only the heater was custom built; the frame and hydraulic components were purchased as off-the-shelf items to expedite the welding tests. A schematic of the prototype apparatus is shown in Figure 2. The prototype apparatus can be refined for high-volume waste management operations by

*Commercially available pipe welding equipment is described in Appendix C.

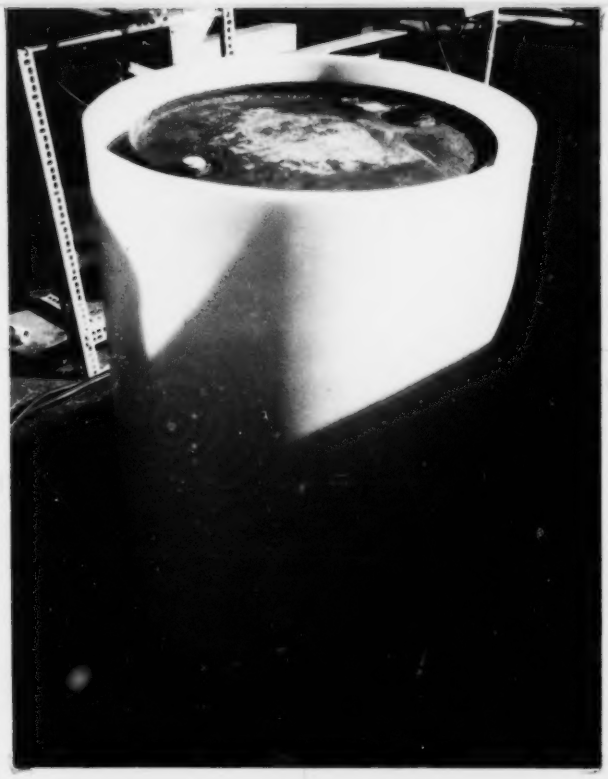


Figure 1. PE receptacle holding 208-liter (55-gal) drum.

incorporating more custom-designed components. This will be delegated to future studies after proving applicability of plastics welding to encapsulate fabrication. Discussions of several of these alternative custom component designs are presented in Appendices D, E, and F.

Frame

The primary function of the frame was to position PE receiver, PE cover and heater. It was determined that the most readily available frame was a steel H-frame. These frames were available from several sources and were used in a variety of manufacturing and testing operations. The frame employed in the prototype apparatus was an Enerpac 7531 H-frame, rated at 76,400 kg (75 tons). Although this frame was oversized on a load capacity

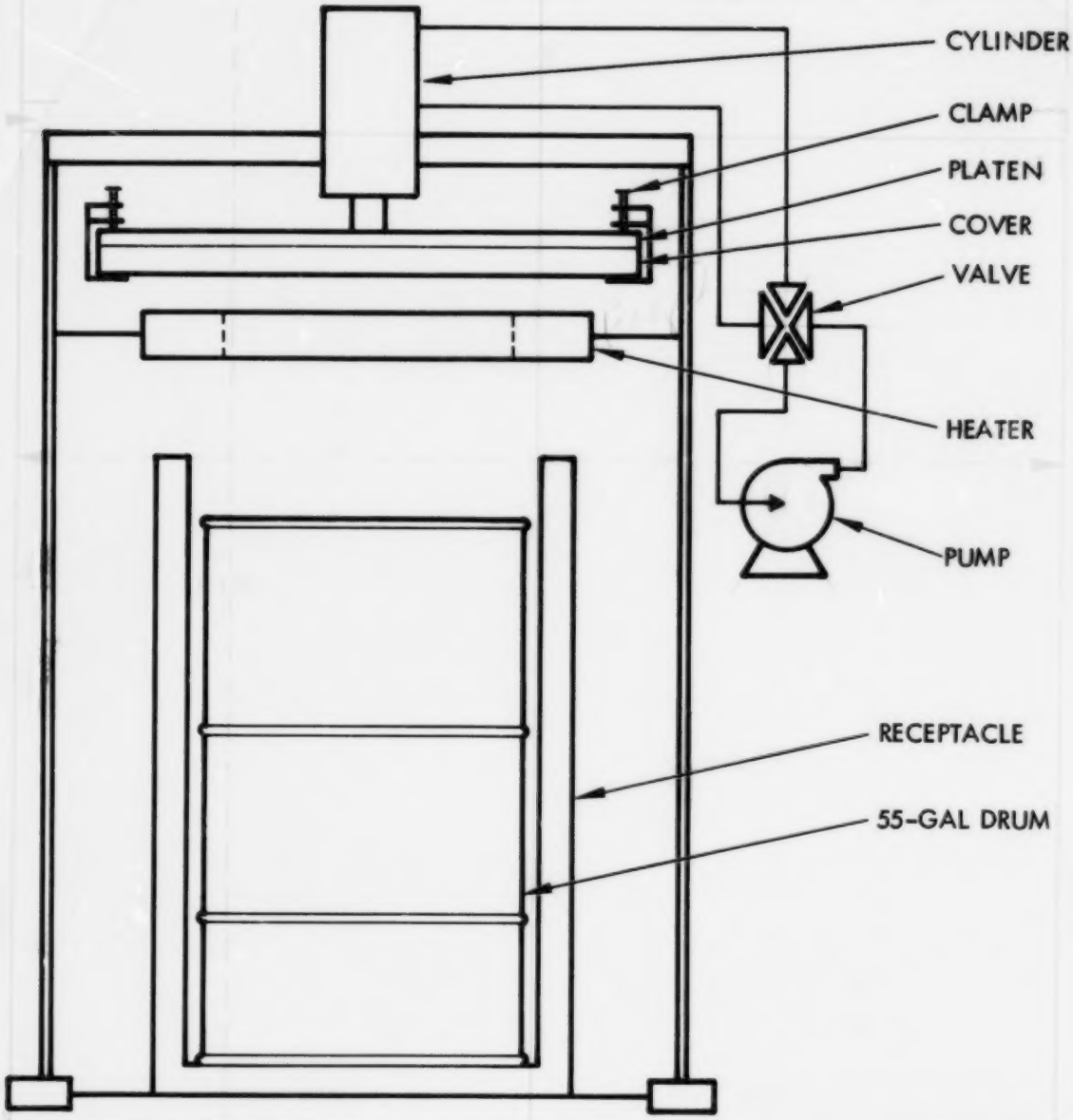


Figure 2. Apparatus for encapsulating 208-liter (55-gal) drums holding hazardous wastes.

basis, it was the smallest frame which had the bed diameter needed to position the receiver. Because the receivers were approximately 76.2 cm (30 in.) in diameter, the distance between the uprights of the H-frame had to be approximately 88.9 cm (35 in.) so the receivers could be placed easily in the frame. The Enerpac press frame was fitted with a movable bed. This bed was useful for welding tests on shortened receiver segments. The overall height of the frame was 193 cm (76 in.) and the width was 129.5 cm (51 in.). The weight of the frame is approximately 727 kg (1600 lb).

A square aluminum platen was made for positioning the PE cover during the fusion operation. The platen was attached to the ram of the hydraulic cylinder so that the cover could be moved vertically. The platen measured 81.3 x 81.3 x 1.27 cm (32 x 32 x 1/2 in.) and was attached to the cylinder at the platen's center; the cover was attached to the platen with C clamps. The platen and flatstock cover were larger than the receiver rim so the cover of the welded encapsulate would overhang the receiver rim. The overhanging cover was used so that the clamping devices would not interfere with the cover-heater contact during the heating of the cover. The platen was cut square to accommodate flat covers, which are readily cut from PE flatstock.

Hydraulic System

The hydraulic system consisted of an electrically driven pump, a hydraulic cylinder, hoses, and the necessary valving. The hydraulic system moved the PE cover vertically to provide clearance for positioning the heater and applied the welding pressure necessary to achieve a waterproof weld. The primary performance parameters were: (a) changeover time* of less than 5 sec, and (b) pressurization of the plastic pieces up to 2.07 MPa (300 psi). The first criterion (quick changeover) prevented skinning, or the formation of a thin layer of solid polyethylene after the heater was removed from the polyethylene pieces. This condition was met by using a high-capacity, two-stage, 1.1-kw (1 1/2 hp) electric pump and a double-acting cyclinder to move the platen to which the cover was clamped. The second criterion was met by using the aforementioned pump, which was rated to 3.45 MPa (5,000 psi).

The pump selected was an Enerpac PER-3042 with a 4-way remotely controlled electric solenoid valve. This pump consisted of a first stage rotary pump which permitted a fast takeup in the cylinder's free travel distance (i.e., before the load was contacted). By using a four-way electric solenoid valve and a double-acting cylinder in conjunction with the two-stage pump, the cover moved quickly in both vertical directions and changed directions rapidly. Illustrations of the four-way valve and double-acting cyclinder are shown in Figures 3 and 4. The pump provided flows of over 3 gpm up to 1.38 MPa (200 psi) and over 2 gpm at 2.76 MPa (400 psi). The pump was rated at 3.10 MPa (4500 psi) continuous duty running cycle to provide the pressure necessary for fusion. The cylinder used was an Enerpac RR-1010 rated at 10 tons with a 25.4-cm (10-in.) stroke.

*Time lapse between removal of heater (from receiver-heater-cover contact during heating) to application of welding pressure.

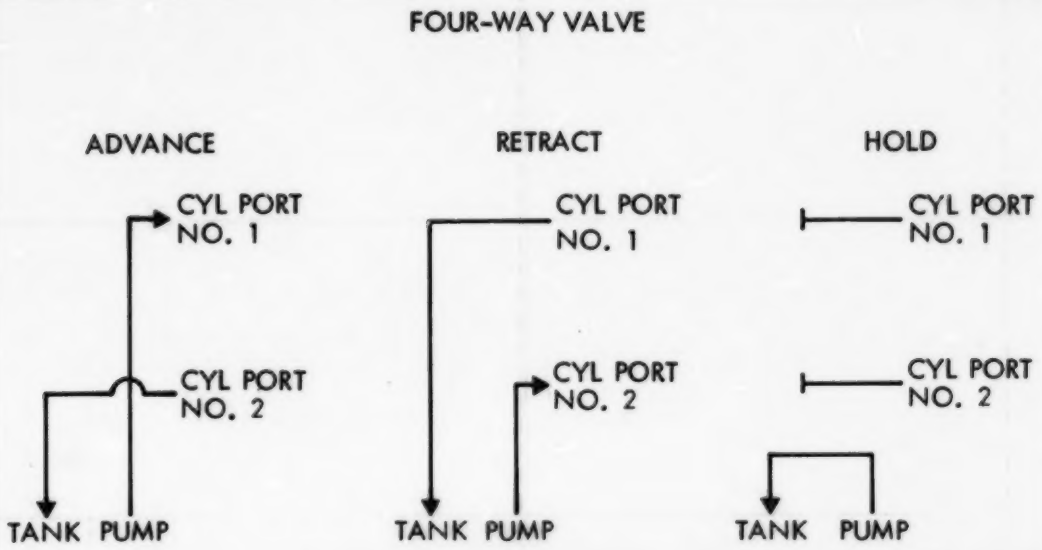


Figure 3. Schematic of four-way solenoid valve.

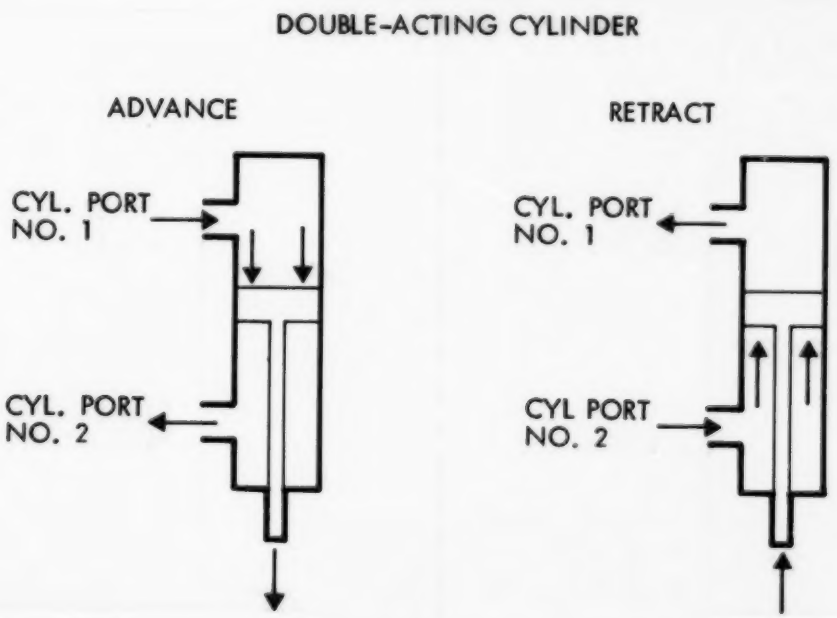


Figure 4. Schematic of double-acting cylinder.

This cylinder provided enough free travel distance to remove the heater easily from the space between the melted PE pieces during the encapsulation operation.

A valving system located between the pump outlet and the top cylinder port was fabricated to prevent overpressurization, and to facilitate testing of different welding pressures. This system also allowed the polyethylene pieces to be heated under a slight pressure termed "kiss" pressure. A schematic of the valving circuit is shown in Figure 5. This circuit consisted of four manually operated ball valves and three pressure relief valves set to open at different pressures. A specific fusion or kiss pressure was selected by opening the ball valve upstream of the specified pressure relief valve and closing the other ball valves. Different fusion and kiss pressures were achieved during encapsulation by first opening the ball valve upstream of the low pressure relief valve. After the cover and the receiver rim were sufficiently melted and the heater was removed from the area between the polyethylene pieces, the ball valve upstream of the low pressure relief valve was closed and a ball valve upstream of the desired relief valve was opened.

The ball valve without a corresponding relief valve was used to bypass the relief valves or to instantly relieve the hydraulic pressure. Research by P. Barber and J. R. Atkinson[5,6] showed that the most successful PE butt welds were produced when the pipe ends were heated in two stages: first, the pipe ends were heated under a slight "kiss" pressure (1 psi) and then the pressure was relieved while the pipe ends were heated for an additional 45 seconds to 1 minute. Thus after heating the receiver and cover under kiss pressure, the single ball valve was opened and the pressure relieved. Although the commercial pipe welding devices did not have a provision for this two-stage heating, the prototype encapsulation apparatus was designed to realize the optimum welding conditions. The ball valves selected were Whitey series 45 with 1.03-cm (0.406-in.) orifices designed for a low pressure drop under full flow. The pressure relief valves were Nupro series 8CPA check and adjustable in-line valves.

Heater

The heater was a cast aluminum ring heater designed to melt the rim of the receiver and a circular portion of the cover. The design criteria of the heater were that the heater attained a temperature capable of melting the polyethylene pieces and that the heater was easily manipulated. A schematic of the heater is shown in Figure 6. The Dimensions of the heater were 66-cm (26-in.) I.D., 76.2-cm (30-in.) O.D., and 2.54 cm (1-in.) thick. The cast aluminum assured both uniform temperatures and light weight.

The duty of the heater was determined by a standard heat requirement calculation[7]:

$$KW = \frac{\rho_h V_h \cdot C_{ph} \cdot \Delta T}{3412 \cdot t} + \frac{\rho_p V_p \cdot H_{fp}}{M_p \cdot t_2 \cdot 3412} + \frac{A_n \cdot Q_n}{1000}$$

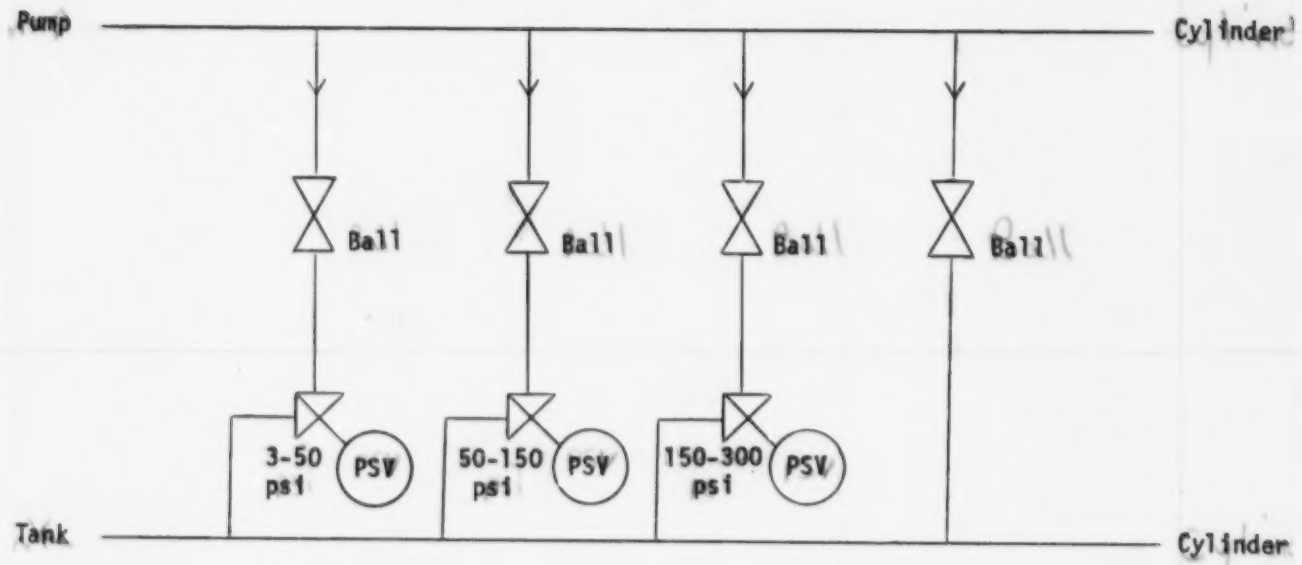


Figure 5. Valving schematic.

where

ρ_h = density of heater, lb/in.^{3}
V_h = volume of heater, in.^{3}
C_{ph} = specific heat of aluminum, Btu/(lb)(^oF)
ΔT = polyethylene melting temperature-ambient
t_1 = temperature, heat-up time, ^oF/hr
ρ_p = density of polyethylene, lb/in.^{3}
V_p = volume of polyethylene, in.^{3}
H_{fp} = heat of fusion, cal/lb-mole
M_p = molecular weight of polyethylene, lb/lb-mole
t_2 = melting time, hr
A_n = area of heater, ft^2
Q_n = heat loss, watts/ft^2

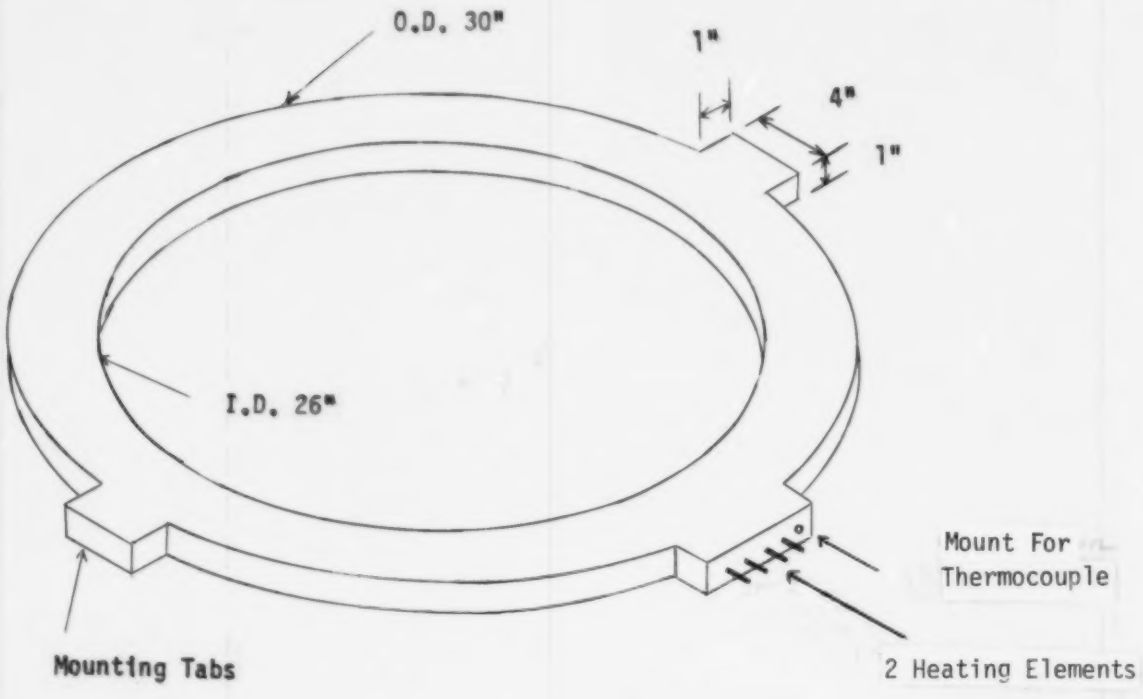


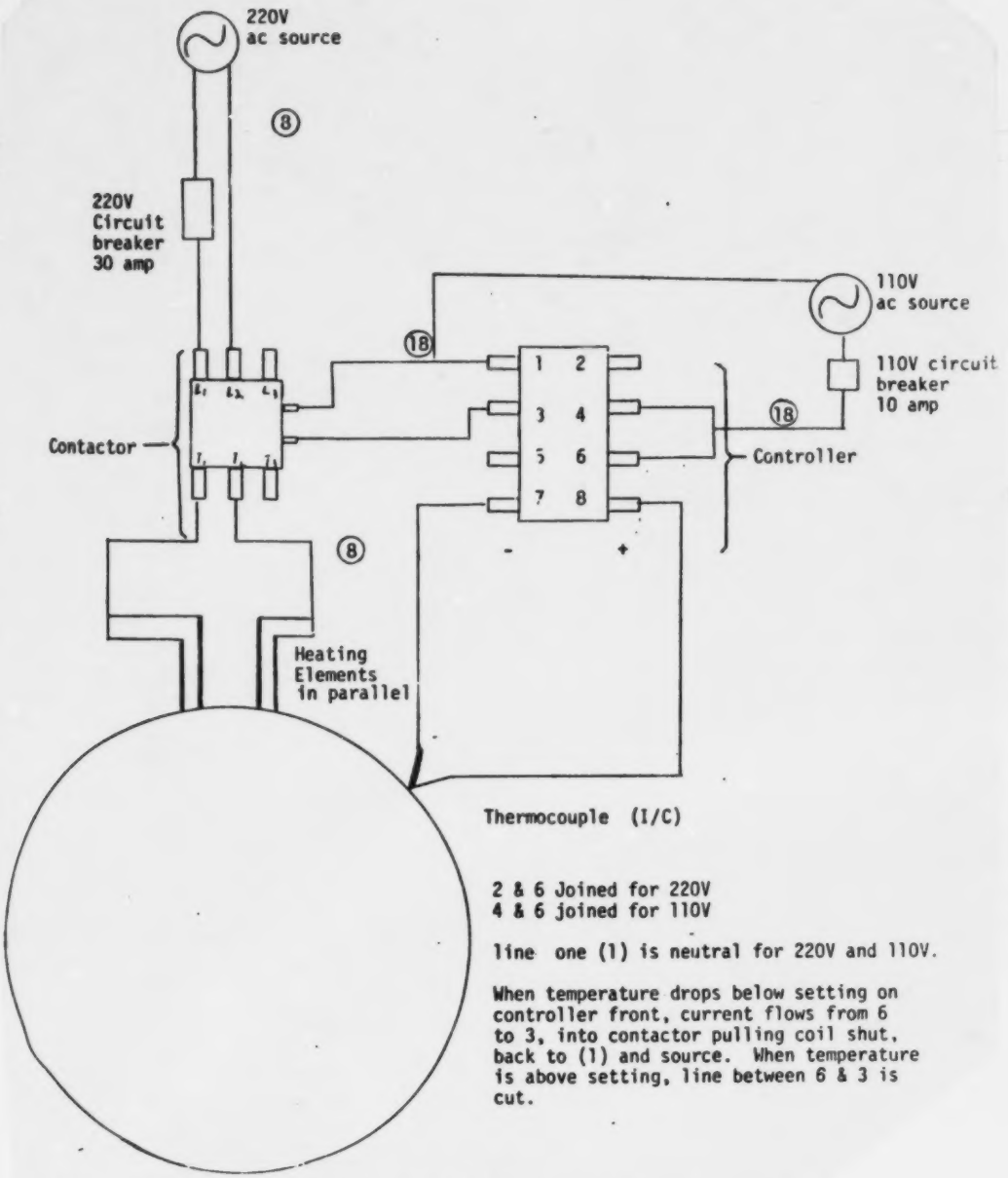
Figure 6. Cast aluminum heater.

The first term determined the power required to raise the heater temperature from ambient to the PE melting temperature; the second term determined the power required to melt PE; and the third term determined the power required to offset the heat loss to the environment. Assuming a heat-up time of 10 min, a melting time of 7 min, and a heat loss of 175 W/ft^2, the heater was rated at 5.5 kW.

Because large-sized ring heaters were not commercially available, the heater was custom built by Fast Heat Corp., Chicago, Illinois. The aluminum was cast around two 2.75-kW heater tubes. The heater was teflon-coated to facilitate demolding of the melted PE from the heater.

A schematic of the circuitry for the heater is shown in Figure 7. A thermostat and thermocouple inserted in the heater made up the major elements of the circuit to control the heater's temperature. This circuit was run from a 110-V AC source, whereas the heater's power circuit was run from a three-phase 220-V AC source. The thermocouple used was iron-constantan, and the thermostat selected was Fast Heat Model 101 proportional temperature controller.

To manipulate the heater, a heater holder was designed and built from stock materials. As mentioned previously, the heater needed to be easily manipulated to achieve a quick changeover time. The heater must be moved horizontally and vertically to effect proper demolding of the melted PE from the heater. After the cover and receiver were melted, the cover was raised from the heater. The heater was then lifted from the rim of the receiver and swung away from the polyethylene pieces. The heater was designed with three tabs protruding one inch from the heater's outer circumference located 90^0 from each other. A semicircular steel brace was attached to the tabs of the heater which served to hold the heater rigidly during welding. The steel brace was welded to steel bars which were welded to a sleeve. The sleeve fitted over a short segment of pipe which was mounted on the press frame. A pulley and hand winch arrangement moved the sleeve and heater vertically, and the sleeve rotated the heater around the pipe's axis. Changeover times of less than four seconds were achieved using this heater holder in conjunction with the hydraulic system. (The heater holder is depicted in Figure 8).



Circled numbers indicate guage wire (8 & 18), all dead metal will be ground.

Figure 7. Heater circuitry diagram.

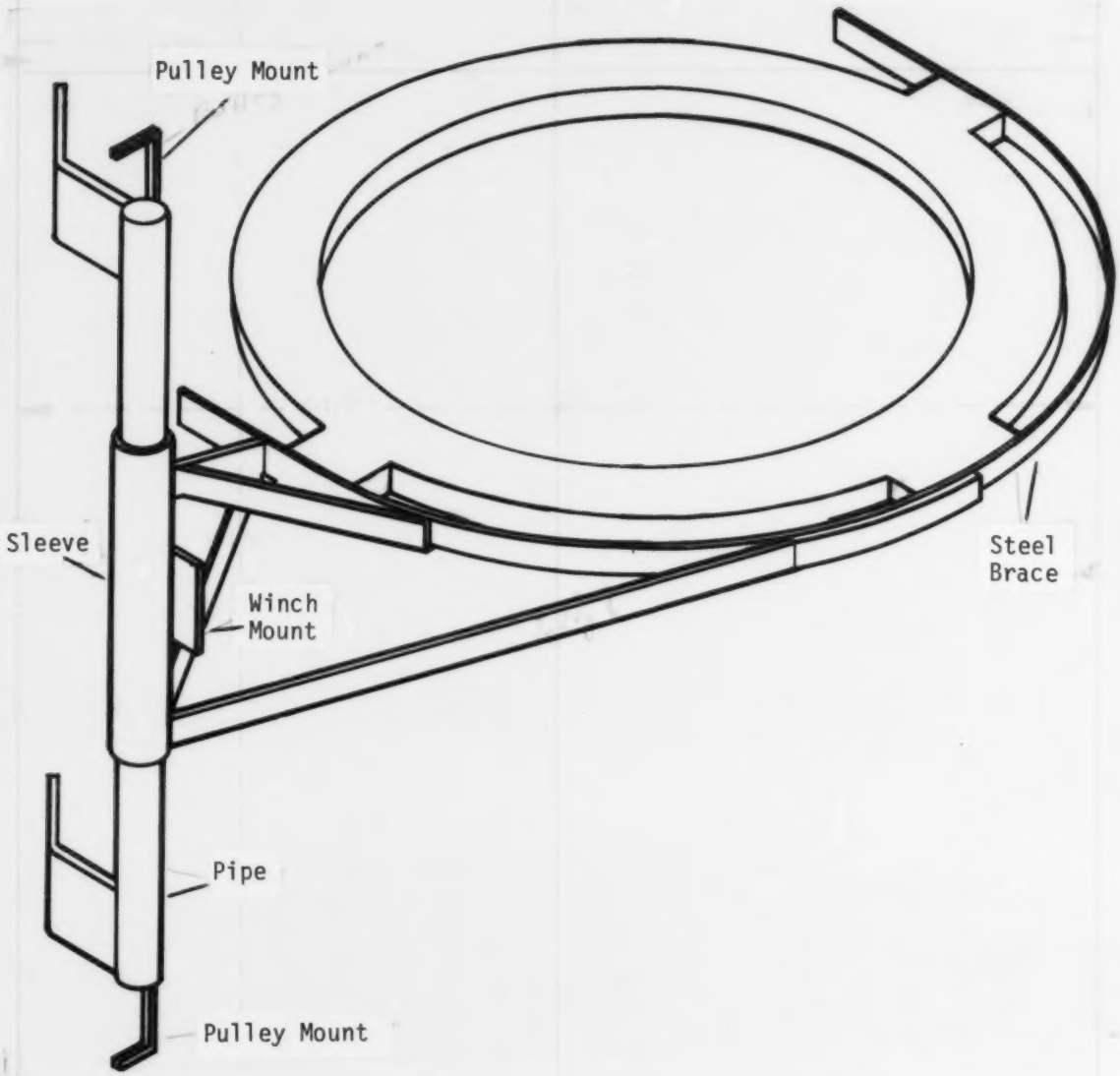


Figure 8. Heater mounted on heater holder.

SECTION 5

ENCAPSULATE FABRICATION

This section details the fabrication of a PE encapsulate of a 208-liter (55-gal) drum by plastics welding. Pipe welding is then compared with encapsulate fabrication to show significant similarities and differences in the two processes. Of the two processes, encapsulate fabrication is concluded to be the simpler to carry out.

ENCAPSULATION PROCEDURE

The encapsulates were fabricated as follows:

1) A 208-liter (55-gal) drum was first inserted into the wide-mouth PE receiver. (Because there was adequate free space between the drum and the inside wall of the receiver [Figure 9], a drum could be inserted by a releasable wire harness.)

2) The receiver holding the 208-liter (55-gal) drum was positioned under the H-frame (Figure 10).

3) The cover fashioned from PE flatstock was clamped to the platen.

4) The heater was positioned above the receiver and below the cover. The heater was brought to 450°K (350°F).

5) The cover was lowered onto the heater (Figure 11). A line pressure of about 345 kPa (50 psi) was generated to give a kiss pressure on the cover of about 4 kPa (0.6 psi).

6) After a small, 1.6-mm (1/16-in.) bead of molten PE was observed on the cover, the heater and cover were simultaneously lowered onto the receiver (Figure 12). A line pressure of 69 kPa (10 psi) was generated, which corresponded to a kiss pressure of about 6.9 kPa (1 psi) on the receiver, and about 0.69 kPa (0.1 psi) on the cover.

7) After a small bead was observed on the receiver, the line pressure relief ball valve was opened, and heating was continued for an additional minute.

8) The cover was then raised from the heater (Figure 13).

9) The heater was removed from the welding area (Figure 14).

Figure 9. PE receptacle holding 208-liter (55-gal) steel drum.

Figure 10. PE receptacle and cover positioned in apparatus for welding. In foreground, operator is applying ing surface treatment to heater to facilitate demolding operations.

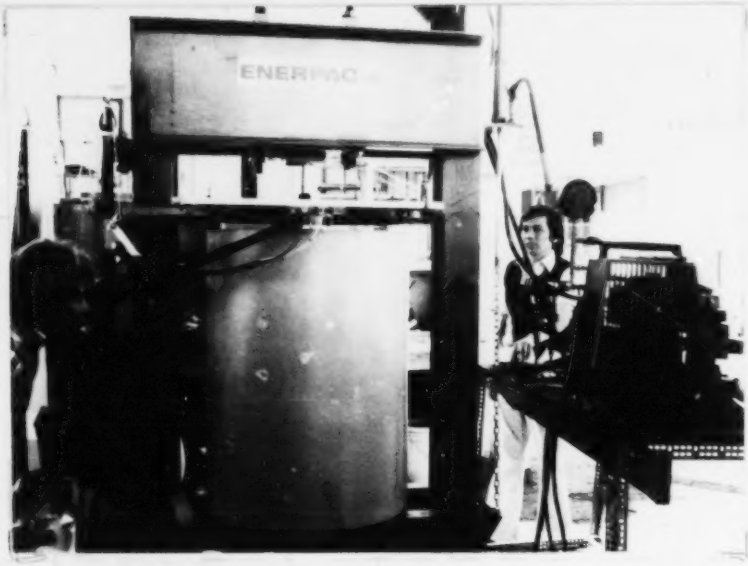


Figure 11. Heating of PE cover.

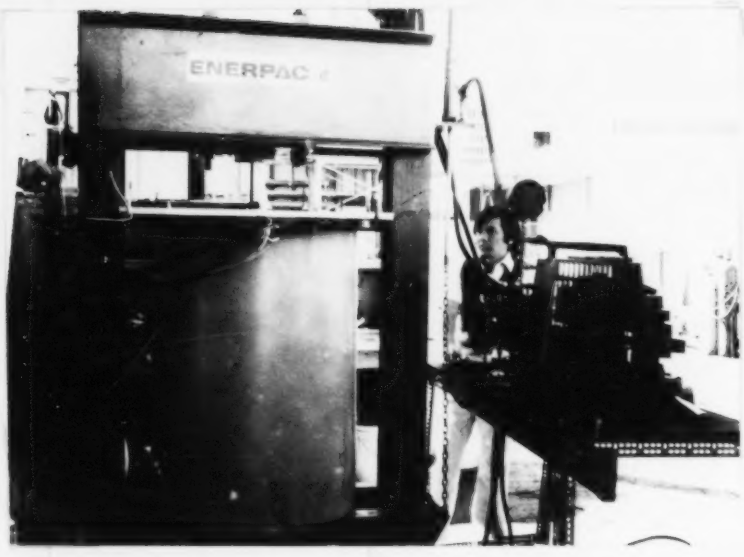


Figure 12. Simultaneous heating of cover and receptacle lip under kiss pressure.

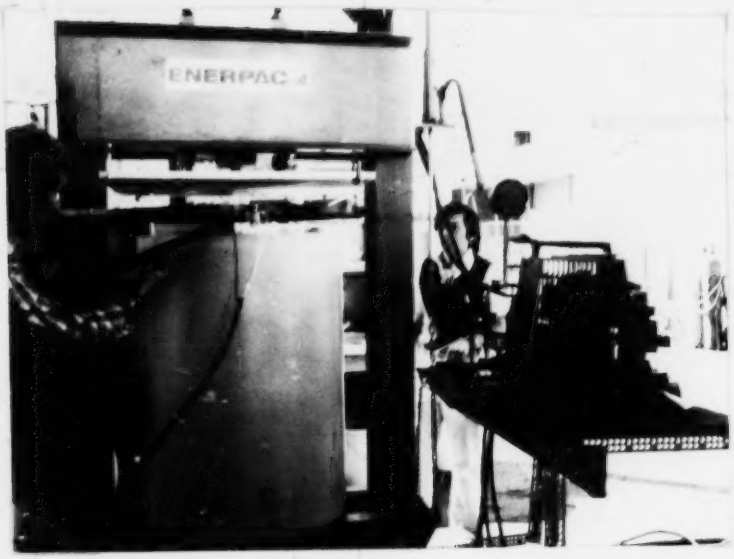


Figure 13. Reversal of hydraulic cylinder.

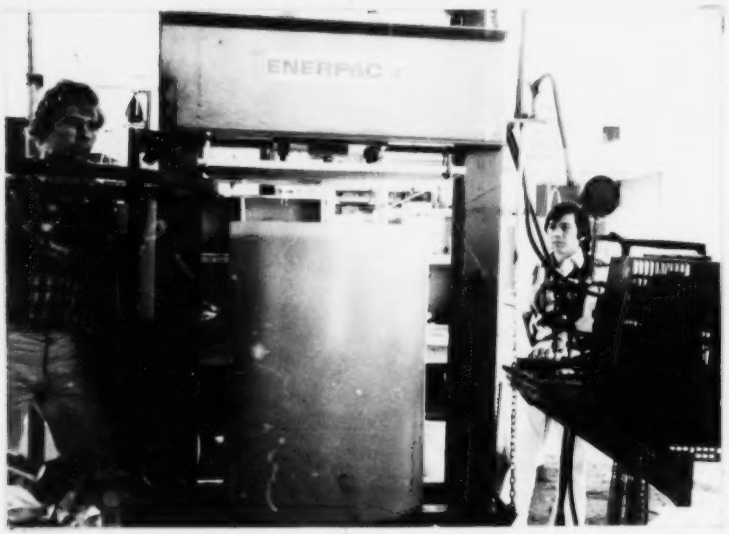


Figure 14. Removal of heater from welding region.

10) The cover was lowered onto the receiver and the line was pressurized to 1.0 MPa (150 psi), which generated a fusion pressure of about 0.1 MPa (15 psi) Figure 15).

11) The weld was cooled under pressure.

12) The clamps were then removed from the cover.

13) The platen was then raised to allow the encapsulated 208-liter (55-gal) drum to be removed (Figure 16).

Figure 17 shows the relationship between line pressure, kiss pressures on the cover and receiver, and fusion pressure. Comparison of curves A and B shows that for a given line pressure, the kiss pressures on the receiver and cover were not equal. The kiss pressure on the cover was smaller than the kiss pressure on the receiver because the heated areas were 1135.8 cm^2 (175.9 $in.^2$) and 140.58 cm^2 (21.79 $in.^2$), respectively. However, for a given line pressure, the kiss pressure on receiver was the same as the fusion pressure (i.e., the weld area was determined by the receiver's cross-sectional wall area).

Comparison of Pipe Welding and Encapsulate Fabrication

The following observations compared pipe welding to encapsulate fabrication:

- During pipe welding, heating of pipe ends (of equal area) occurred simultaneously, whereas in encapsulation, the heating of the cover preceded the heating of the receiver. (The rate of polyethylene melt formation is dependent on both the heater temperature and kiss pressure. Since the heated area of the cover was larger than the heated area on the receiver, the cover was melted at a higher line pressure before the melting of the receiver rim to achieve adquate melt on the cover).
- During welding, pipes were positioned horizontally and end-to-end, whereas receptacles were positioned in an upright position.
- Pipes with diameters comparable to receptacles used for encapsulation had much thicker walls, thus requiring manipulation of heavier pieces.
- Greater weights of pipe involved heavier duty machinery than that needed in encapsulation.
- Greater surface area of pipe required mechanical force at closure to be greater than that needed in welding lids to receptacles.
- Perhaps most important, closure of pipe required careful alignment to match rim to rim, whereas proper fitting of lid to rim of receptacle can be effected with less alignment sensitivity.

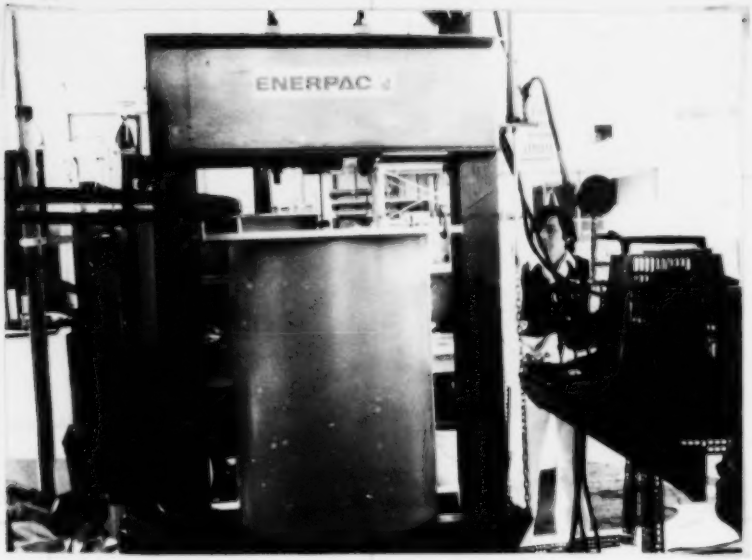


Figure 15. Application of welding pressure.

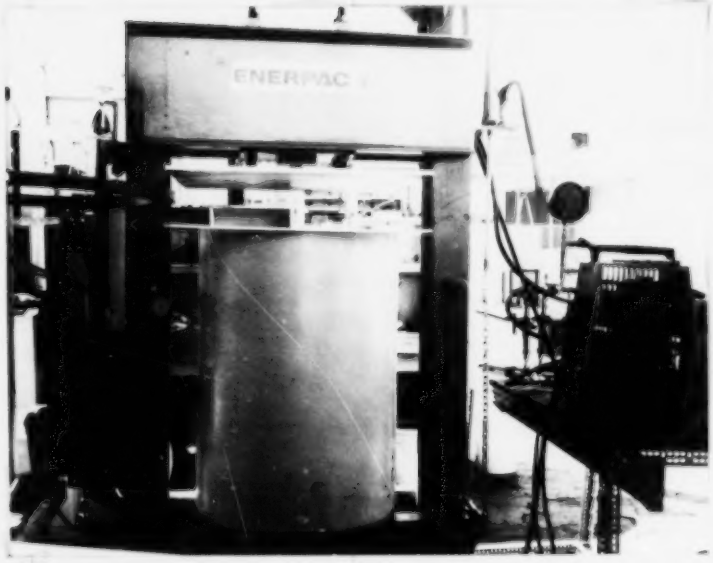


Figure 16. Encapsulated 208-liter (55-gal) drum.

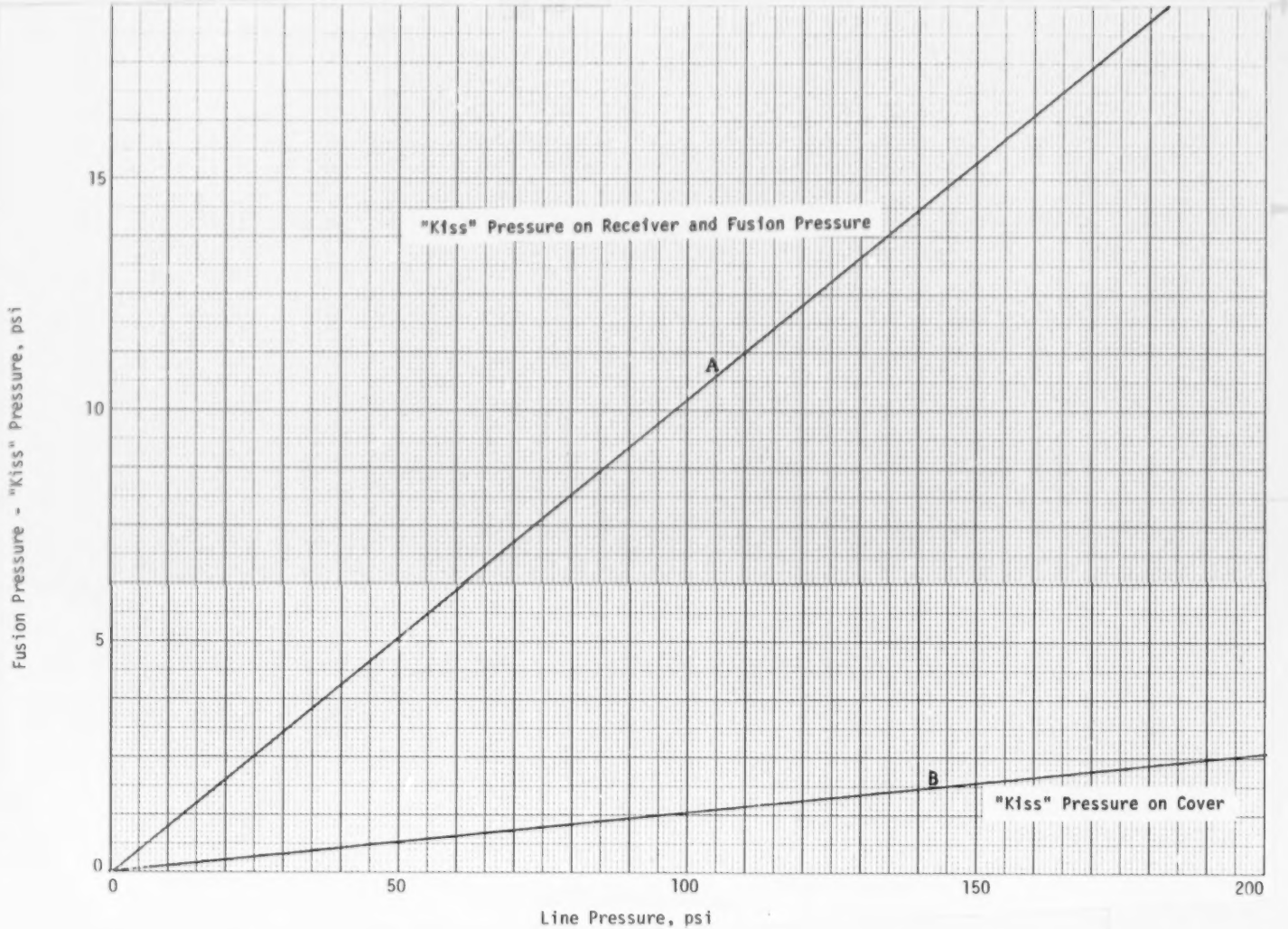


Figure 17. Fusion and kiss pressures versus line pressure.

SECTION 6

ENCAPSULATE CHARACTERIZATION

Welded encapsulates were found to be watertight overpacks for 208-liter (55-gal) drums. They were expected to preclude effectively the contact of hazardous waste consignments with aggressive environmental waters even though the drums within might continue to corrode. An estimate of performance was obtained by inspection and testing of the welded joints of PE covers and receivers.

NATURE OF THE WELDED JOINTS

To investigate the nature of the welded bond, the top portion of a welded plastic encapsulate was removed. Figure 18 shows that segmented specimen. A close visual inspection of the weld showed the formation of a continuous, solid, resinous bead surrounding the welded interface (Figures 19 and 20). The bead was approximately 0.95 cm (3/8 in.) thick. To investigate the watertightness of the welded bond, the specimen was charged with water containing a high-visibility dye which was detectable at 1 ppm. Over a period of 4 months no leakage was observed (Figure 21).

Several PE receiver-cover welds were inspected by optical microscopy to determine the quality of the welded bonds. The optical micrographs showed that the welds were continuous, void-free structures which should exhibit the high strength properties expected of high-density PE. Figure 22 is an optical micrograph of a cross section of a receiver-cover welded joint taken under reflected light. The specimen was prepared by sectioning a full size specimen across the welded zone, mounting the section in epoxy resin, and polishing the sample. This micrograph showed that a portion of molten PE was flashed to the side of the receptacle-cover interface. This flashing of molten PE should result in strong bonds since the weld thickness is greater than the receptacle's wall thickness.

To investigate further the microstructural characteristics of the weld, a thin cross-section was mounted in a transparent medium, and transmission optical micrographs were obtained. These micrographs showed the welds to be continuous, voil-free regions in which good wet out and mixing of receiver-cover materials occurred.

Figure 23 shows several regions across a weld which were examined by transmission optical microscopy. These regions are shown at higher magnification in Figures 24 and 25. Regions A, B, C, and D in Figures 24 and 25 show dark and light materials separated by an interfacial area intermediate in color. The darker material was high-density PE, which transmits less

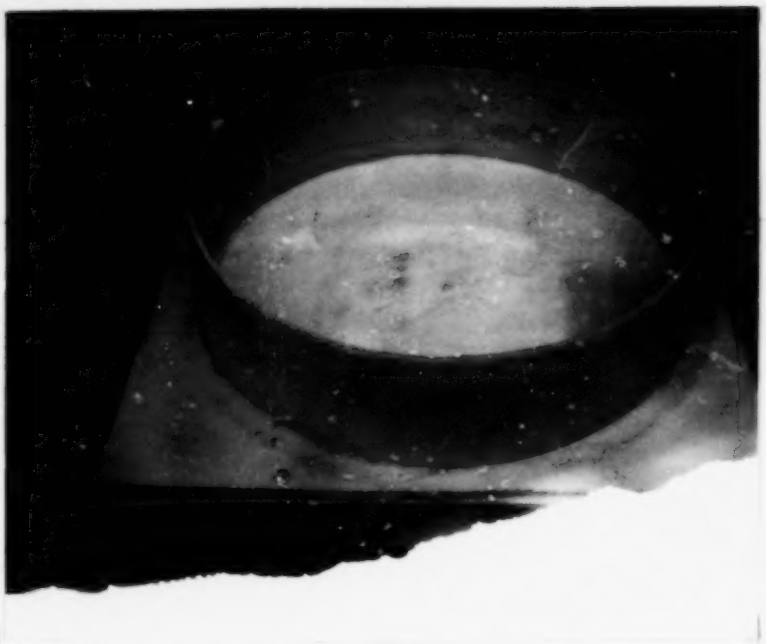


Figure 18. Cross-sectioned encapsulate showing receiver-cover weld.

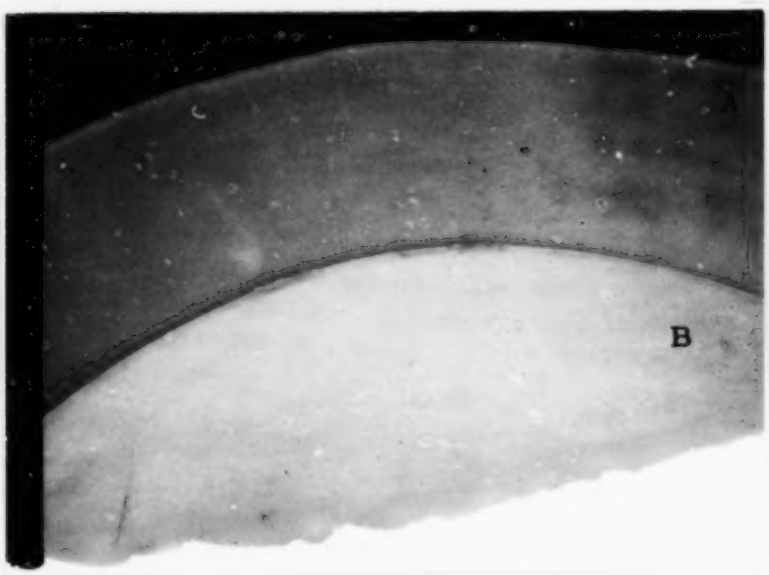


Figure 19. View of inner circumference of weld: A, receiver section; B, flat stock section.

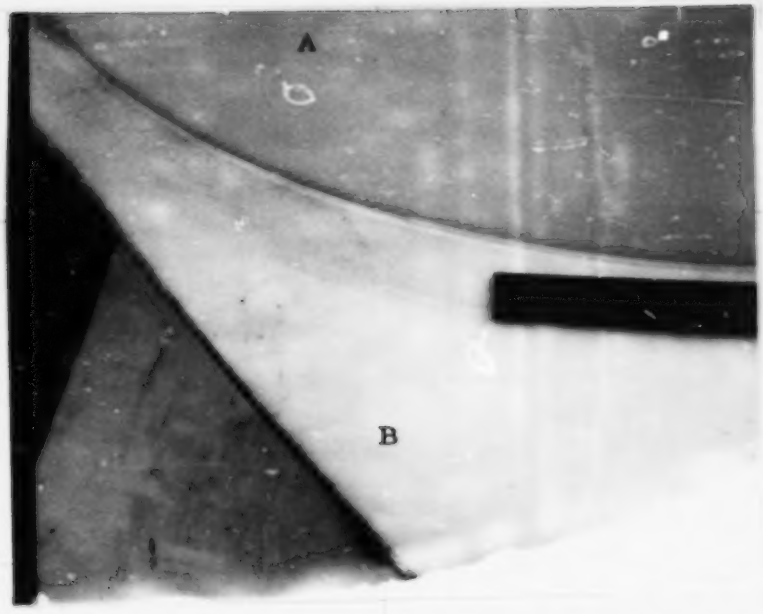


Figure 20. View of outer circumference of weld: A, receiver section; B, flat stock section.

Figure 21. Water-tightness of weld demonstrated using solution containing high-visibility dye.

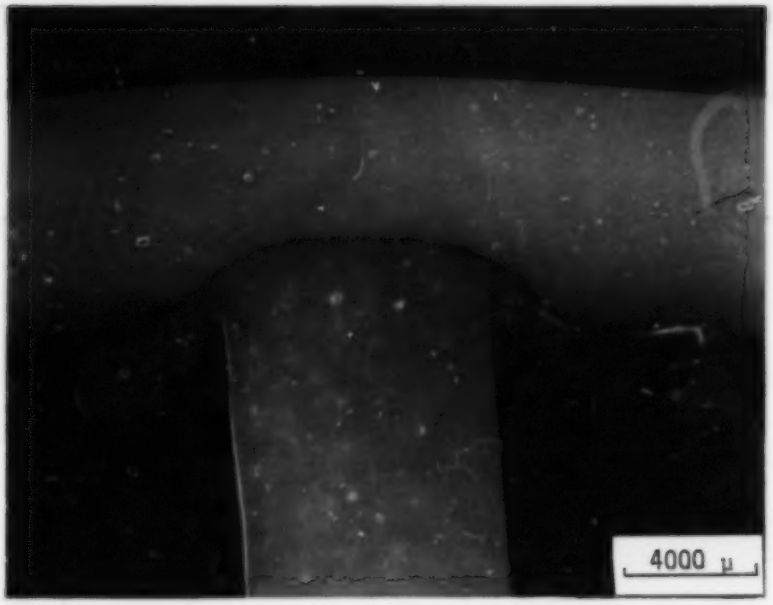


Figure 22. Optical micrograph (5x) of polished cross section of PE receiver-cover weld.

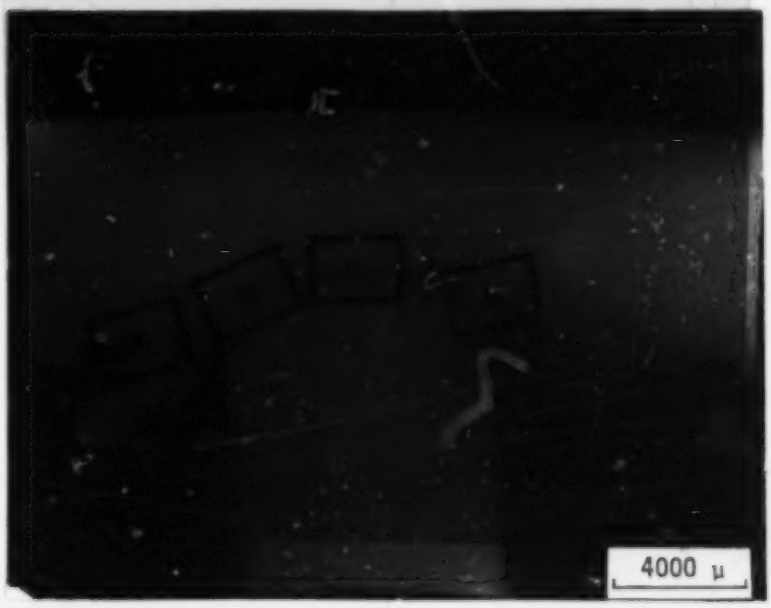
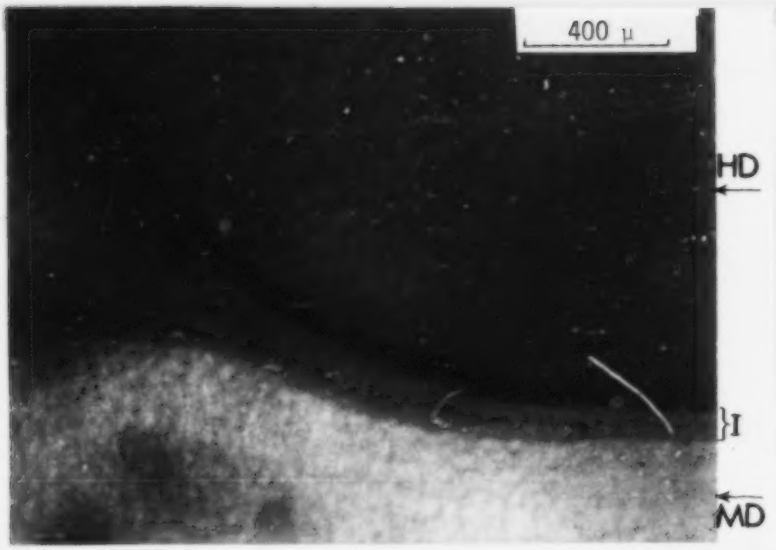
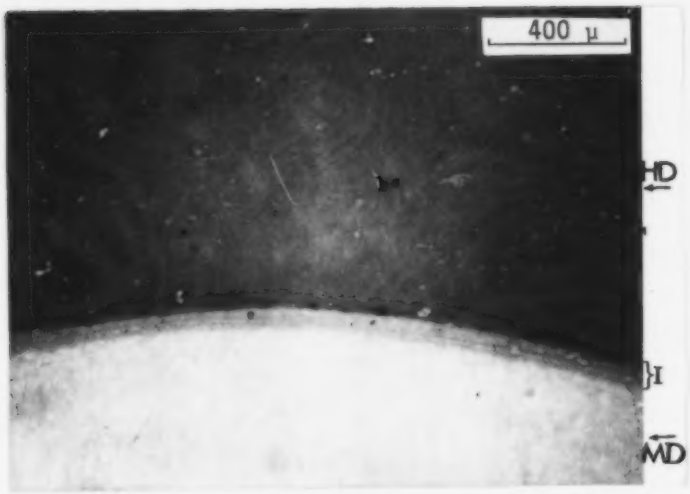


Figure 23. Optical micrograph (5x) showing weld regions designated for transmission optical micrographic study.

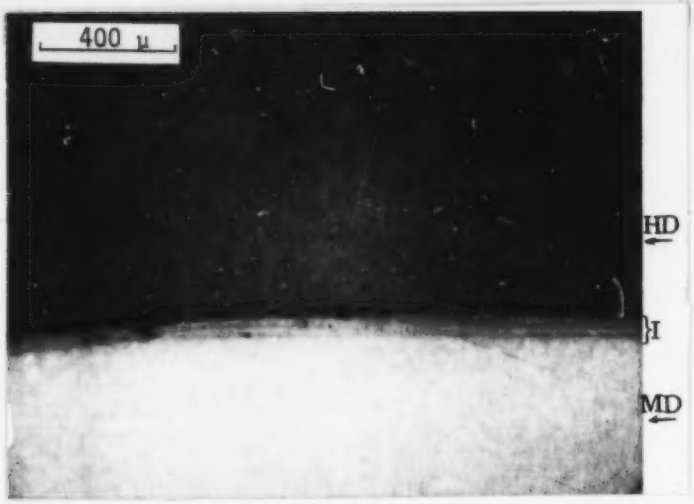


REGION A

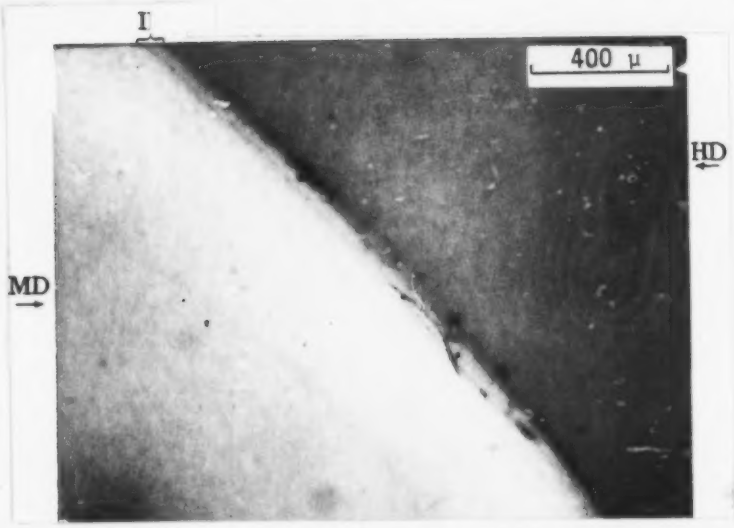


REGION B

Figure 24. Transmission optical micrographs of weld regions A & B identified in Figure 23.
HD - high-density polyethylene cover.
MD - medium-density polyethylene receiver.
I - interfacial area.



REGION C



REGION D

Figure 25. Transmission optical micrographs of weld regions C & D identified in Figure 23. HD - high-density polyethylene receiver. MD - medium-density polyethylene receiver. I - interfacial region.

light than the medium-density resin. The interfacial area, where mixing occurred, was intermediate in color and was presumed to have an average density between that of the two parent materials.

Regions B, C, and D show the interfacial area to be approximately 60 microns across. These were regions directly between the receiver wall and cover during welding. Region A shows wider and more diffusive structure, which was the material adjacent rather than between the wall and cover; as a result, this portion of the bond was formed at lower fusion pressure.

Figures 26 and 27 show the ruptured interfaces of sections of a welded joint that were mounted on a vise and repeatedly flexed along the weld. Microscopic inspection of welded interfaces showed necked or drawn fibrous structures on both cover and receiver; and some specimens exhibited failure across the receiver section. These observations, strong adhesion and cohesive failure, are indications of high-strength bonding.

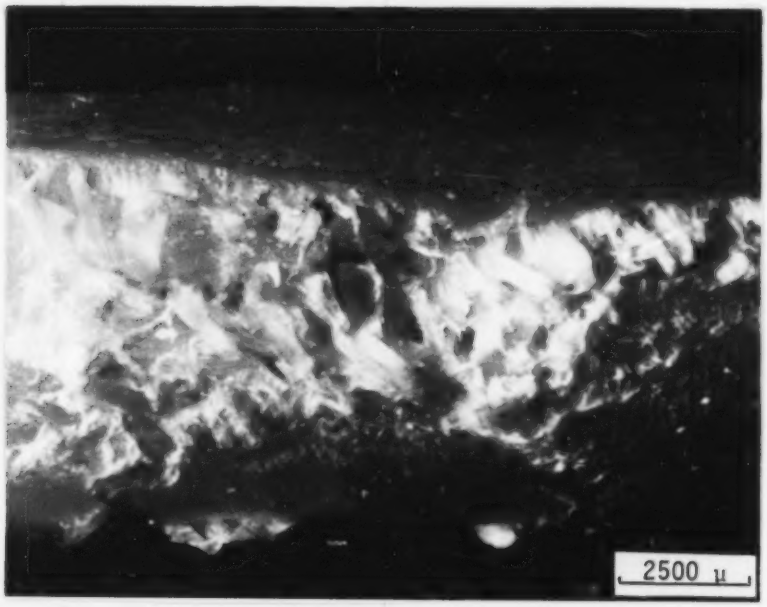


Figure 26. Optical micrograph (8x) of PE receiver section of welded joint after rupture resulting from repeated flexing.

Figure 27. Optical micrograph (5x) of cover section of welded joint after rupture resulting from repeated flexing.

STRENGTH OF WELDED JOINTS

The mechanical performance of encapsulates was characterized by noting the behavior of welded specimens in tension. These tests showed that encapsulate welded joints are capable of withstanding high mechanical loads and will undergo appreciable elongation before rupture.

Preparation and "Fixing" Tensile Specimens

In order to determine the strength of welded joints in tension a special testing procedure and fixture were employed. Usual tensile tests and welded pipe tensile tests were not applicable due to the T configuration of welded joint specimens. A special fixture was employed to fix the specimens for testing and to assure that the applied load was across the welded bond.

Sections across the weld were obtained from the specimen shown in Figure 18. Next, each specimen's cross section at the weld was machined to a 0.806 cm^2 (0.125-$in.^2$) area using a 2.54-cm (1.00-in.) SE Ball/Rotary Mill. The resulting tensile specimen's configuration was that of a T which

was narrowed at the juncture (Figure 28). To apply tension normal to the cover section and parallel to the receiver section, a matching aluminum T fixture was made (Figure 28, C). Specimens were mounted with clamps (Figure 29) and tested using an Instron Universal Testing Instrument, Model 1130, at a head speed of 50.8 mm (2 in.) per minute.

Test Results

Figure 30 shows a welded joint under high tensile stress. The specimen has appreciably elongated in the vicinity of the weld without rupture. Rupture occurred (Figure 31) at about 20.1 MPa (3000 psi) and after 38% elongation. Close inspection of ruptured specimens showed rough interfacial characteristics similar to those described for Figures 26 and 27.

Figure 32 is a typical stress-strain curve for welded joints. The initial vertical rise indicated bonds could withstand very high tensile stresses (about 12.4 MPa, or 1800 psi) without distortion. And upon additional loads (20.1 MPa, or 3000 psi), they would continue to perform by elongation. (Polyethylene specimens typically yield at tensile stresses around 22.1 to 29.6 MPa, or 3200 to 4300 psi,[8] when tested by traditional ASTM methods). Table 1 lists average values for tensile tests.

TABLE 1. PROPERTIES OF WELDED POLYETHYLENE SPECIMENS

Property	International System		English System	
	Value	Unit	Value	Unit
Tensile Strength*	19.9	MPa	2880	psi
Strain at Break	38	%	38	%

*Based on original cross-sectional area of weld.

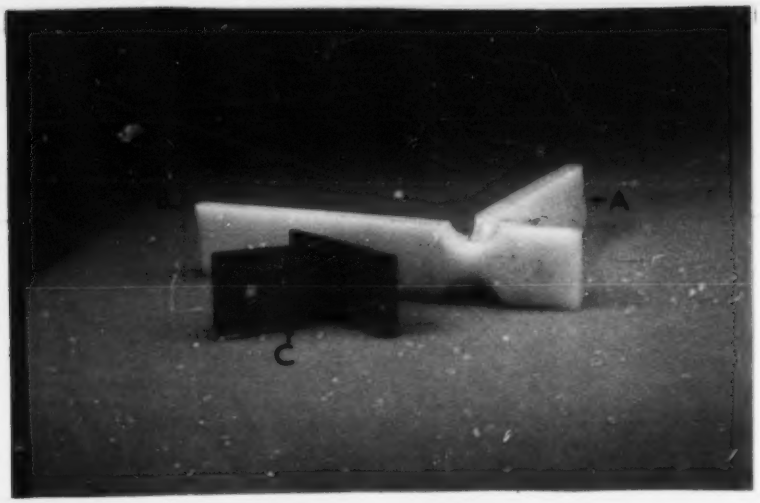


Figure 28. Tensile specimen and tensile fixture: A, receiver section; B, cover section; C, aluminum T tensile fixture.

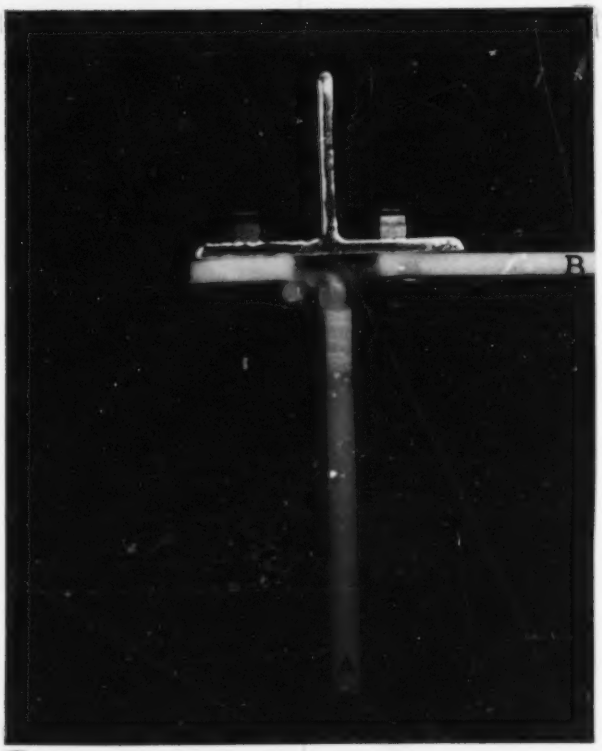


Figure 29. Specimen mounted onto tensile fixture: A, receiver section; B, cover section.

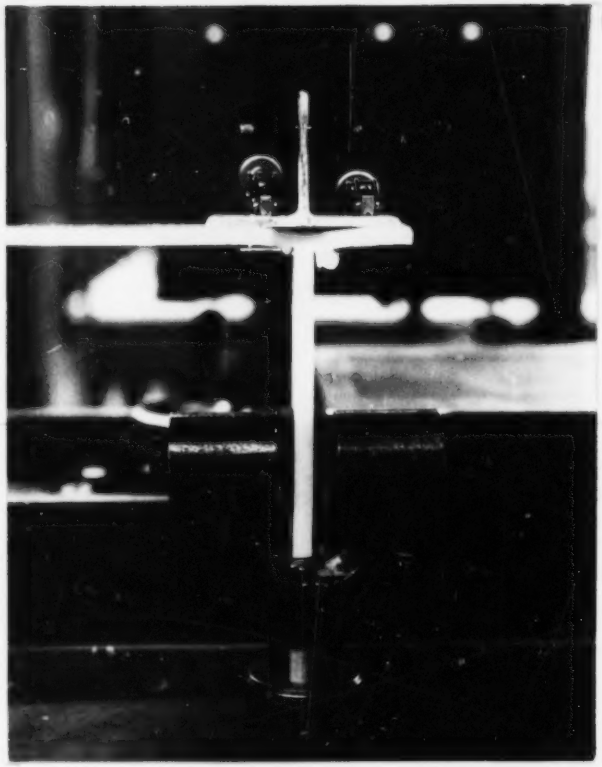


Figure 30. Welded joint under tension.

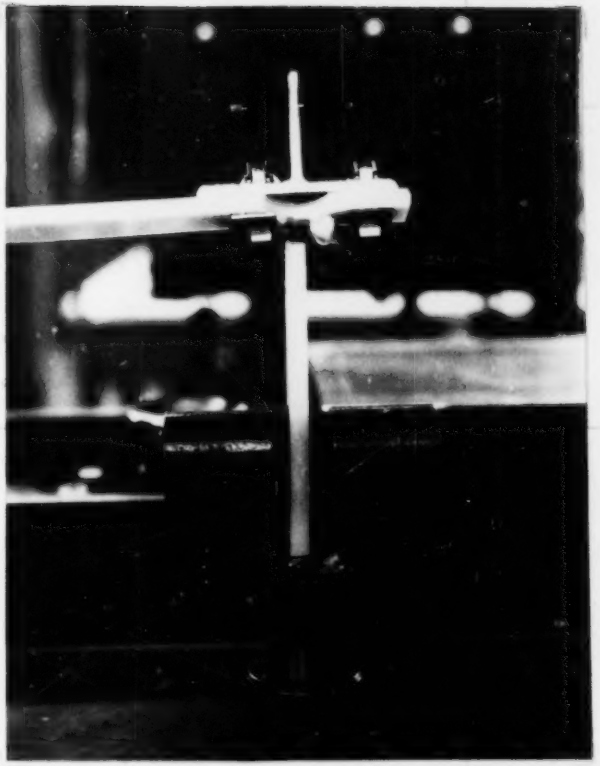


Figure 31. Ruptured welded joint.

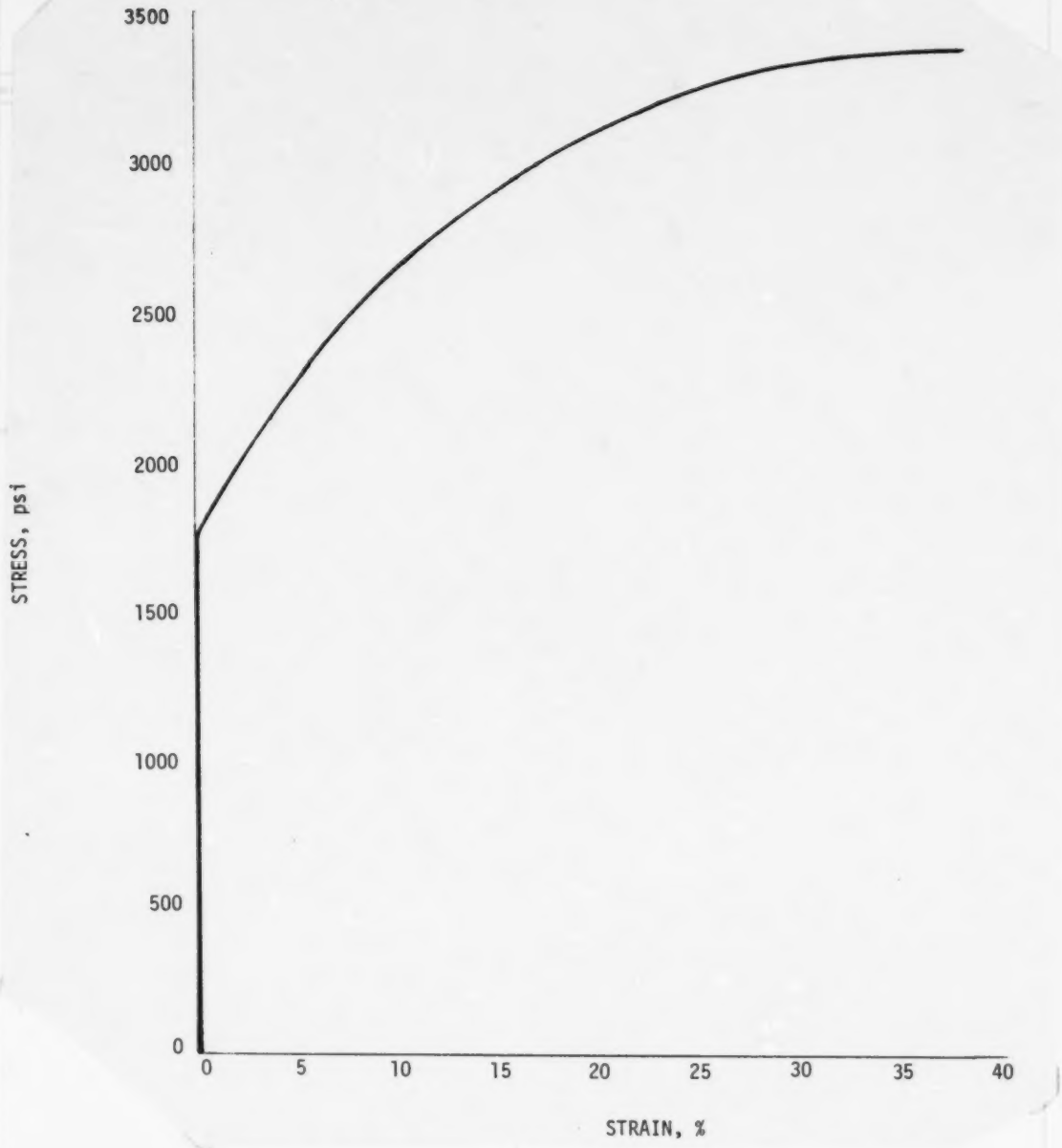


Figure 32. Stress-strain curve for welded PE joint.

SECTION 7

PRELIMINARY ECONOMIC EVALUATION

Costs associated with the process were investigated to compare the plastic welding encapsulation process with other hazardous waste management options. Table 2 presents the results of a preliminary economic analysis of the plastic welding encapsulation process. Table 2 shows that the major costs were due to the consumable material costs (i.e., the PE flat stock and receivers). Labor and capital equipment costs were negligible compared with the consumable material costs. Other costs, such as utilities, were estimated to be also minor, even when including the contingency factors.

An important feature of the plastic welding process for managing hazardous wastes was the capability of processing the drums on site, i.e., the drums did not need to be moved off site for encapsulation. This feature reduced the risk of damaging the drums and spilling their contents prior to encapsulation. In making the cost estimates, it was assumed that all the drums were located at one site so that processing and equipment movement costs were not included. It was assumed that the drums were manageable (i.e., the drums had not deteriorated so that their contents would be spilled upon lifting). (Though the plastic welding technique was still appropriate for badly deteriorated drums, the cost of handling the drums before encapsulation would be estimated differently.) The cost of the encapsulation process was based on the following four steps:

1. Assembly of Materials. The receivers and flatstock covers are positioned near the encapsulation apparatus. It is assumed that the major items of capital equipment (forklifts, hoist, conveyor belts, encapsulation apparatuses, etc.) are positioned at the site and ready for use. It is assumed that one man is sufficient to operate the drum assembly operation.

2. Positioning Drums. This step involves lifting the drums with a forklift onto a conveyor belt. The belt then moves the drums to a hoist. The hoist then lifts the drums, the receivers are positioned under the drums, and the drums are lowered into the receivers. Either one of two operations during this step can limit the rate at which the drums are processed: the drum retrieval with the forklift, or the drum placement with the hoist. It is estimated that a forklift can retrieve two drums and place them on the conveyor in 3 min. Consequently, one hoist is needed to process 40 drums/hr. The extra hoist

TABLE 2. PRELIMINARY ECONOMIC ANALYSIS

Plastic Welding Process for Encapsulating 55-Gal Drums

Basis: 20,000 Tons per Year
80,000 Drums per Year
(Drums Contain Liquid Waste - Density $\sim$ 64.6 Lb/Ft^3)
(Drums assumed to be located at one site)

	Capital Costs	Consumable Materials Polyethylene Receivers + Flatstock	Labor
Costs	3 Forklifts @ 15000 ea. = 45,000 1 300 Ft. Conveyor = 20,000 2 Hoists @ 1500 ea. = 3,000 7 20 Ft. Conveyors @ 1000 ea. = 7,000 7 Encapsulation Apparatus @ 1000 ea. = 7,000 Equipment Costs 82,000 10% Contingency 8,200 Total $90,200	$/Unit Vendor # Units† A B C D 5,000 $65 70 75 75 10,000 50 55 65 70 50,000 45 45 50 70 Average Cost = $60/Unit	8 Men @ $10/Hr = $80/Hr 1 Supervisor @ $15/Hr = 15/Hr Labor = $95/Hr 20% Overhead 19/Hr Total $114/Hr
Costs/Year	Capital Costs Amoritized At 15% Over 5 Years = $45,000/Year	Yearly Costs = Cost/Unit x Units/Year $4,800,000/Year	Yearly Costs = 250 Days/Year x 8 Hrs/Day x Labor Rate/Hr $228,000/Year

†Unit = 1 Receiver + Flatstock Cover

TOTAL COSTS = $5,073,000/Year
= $253/Ton
= $63.40/Drum
= $8.13/Cu. Ft.

Costs are based on six encapsulation apparatuses operating one 8 hour shift/day - i.e., 320 drums/day are processed

Vendor A - Lee Myers, Inc. - Westminster, CA.
Vendor B - Rotational Molding - Gardena, CA.
Vendor C - Hollowform, Inc. - Woodland Hills, CA.
Vendor D - Formation, Inc. - Burbank, CA.

listed under capital costs is a backup. Two men, the forklift operator and the hoist operator, are needed for this processing step.

3. Encapsulating Wastes. The drums containing hazardous wastes are encapsulated using the apparatus developed for the plastic welding process. This involves butt welding a piece of flat stock onto the receiver. The 208-liter (55-gal) drum is now secured in a high performance encapsulate and suitable for landfilling.

   It is assumed that a drum can be encapsulated in 9 min. Seven encapsulation devices are needed to process 40 drums/hr. A centrally located hoist positions the drums into the receivers as they arrive on one of six conveyor belts. The belts then deliver the drums in receivers to the encapsulation apparatuses. It is assumed that one man can operate two encapsulation devices, because a single encapsulation will not occupy all of the operator's time (the plastic welding technique requires that the weld be cooled under pressure for several minutes). Consequently, three encapsulation operators are needed.

4. Unloading. The drums are removed from the machine. In this cost analysis the drums are moved by conveyor from the machine. A forklift is required to remove the encapsulated drums from the conveyor. One forklift operator is required for this step.

In calculating the labor costs, one additional man plus a crew supervisor are included to cover any contingencies. When capital cost is calculated, extra equipment is added to cover breakdowns, malfunctions, etc.

To calculate material costs, four rotomolding companies in the greater Los Angeles area were contacted. The results of the survey are presented in the table as a cost per unit, where a unit is defined as one polyethylene receiver and one flat stock cover. The cost of $60/unit was averaged from the survey (Appendix B). A varying economy of scale is seen for the different manufacturers (i.e., the cost decreases as the number of units ordered increases). The economy of scale for a tenfold increase in units ordered varies from approximately seven percent for Formatron, Inc. to 36 percent for Rotational Molding, Inc. The variation in economy of scale appears to be dependent on the rotomolder's capacity: Formatron, Inc. is a smaller outfit than Rotational Molding (5,000 units utilizes most of Formatron's capacity.) However, even with the cost reduction accompanying large orders, there is still a large margin when one compares the cost of a unit to the raw material costs. It is estimated that the weight of the receiver and flat stock needed for high performance encapsulates is 20.45 kg (45 lb). The current price of blow and injection molding grade high-density polyethylene in hopper car quantities as reported in October 8, 1979 Chemical Marketing Reporter is $0.7975/kg ($0.3625/lb). Consequently, the raw material cost reduction for the process can be realized if the margin between the raw material and consumable material prices can be realized. Also, potential

cost savings may be realized by using scrap polyethylene at $0.374/kg (or $0.17/lb) to fabricate the encapsulates.

Because consumable materials make up the major costs associated with the plastic welding encapsulation process, the long-term outlook for polyolefins (particulary polyethylene) was investigated. It was seen that the price of polyethylene roughly escalates with the price of crude oil. However, new processing technology may ameliorate the projected price increases. Additional points concerning the present status and future market trends for polyolefins (Chemical Week, June 13, 1979, pp. 37-39) are summarized:

- The polyolefin share of the thermoplastic market is greater than 50 percent with
  HDPE 15.2 percent
  PP 11.1 percent
  LDPE 26.0 percent
- U.S. ethylene prices are 30.8¢/kg (14¢/lb)
- Basic prices of HDPE are about 99.4¢/kg (45.2¢/lb)
- Union Carbide's Unipol process promises considerable savings in production costs and improved product performance.
- Domestic consumption of HDPE is 0.49 billion kg (1.08 billion lb) with exports at 68.6 million kg (151 million lb).
- Of all major plastics, polyolefins are among the best positioned for future growth because materials are relatively plentiful and less subject to energy-related problems than some of the competition.
- Annual gains about growth of HDPE are placed at better than 5 to 7 percent.
- The price for ethylene based on reduced crude is projected to be 73.0¢/kg (33.2¢/lb) in 1984, with the consequent increase in price of the plastic being ameliorated somewhat by improved synthesis methods.

SECTION 8

RESULTS AND DISCUSSION

Steel 208-liter (55-gal) drums were encapsulated with PE employing the art of plastics welding. The drums were inserted into wide-mouth PE receivers and then sealed with PE sheet stock (Section 5). Investigations of the welded joints (Section 6) showed strong bonds between receivers and sheet. These results and the progress of the work lead to the conclusions (Section 2) and Recommendations (Section 3) given previously. Questions concerning potential hazards in field operations and material compatibility of PE were not addressed and these are discussed in this issue.

Although hazards associated with emptying drums of contents were not inherent to drum management in this work, potential hazard may be due to organic vapors stemming from drums that may ignite at the heater employed for welding. In addition, the incompatibility of contents of corroding drums and PE was possible because no provision was made for screening incompatible materials.

With respect to the first item of concern, ignition of vapors by the heater was not considered a probable event because the autoignition points of most organic vapors are greater than 450°K (350°F),* the surface temperature of the heater. Furthermore, the temperature of the drum was unaffected by plastics welding: Consequently, combustible concentrations of vapors arising because of atmospheric conditions only was unlikely. It was also considered unlikely that readily vaporizable organic liquids would exist in corroding drums exposed to the atmosphere for long periods of time.

With respect to the second, PE was selected in this work because it had the best chemical stability among plastics that are low in cost and mechanically strong. It also was well characterized, and vendors provided extensive material compatibility data with each type of PE provided to the commercial market. Some chemical advances may characterize other low-in-cost resins but they yielded brittle materials which were unacceptable in this work. PE in our opinion was the most generally applicable, suitable resin. Witness the predominance of PE in commercial containers.

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*Autoignition points (G. Hawley, Condensed Chemical Dictionary, 9th Ed., Van Nostrand Reinhold, 1977) for several common organic solvents are as follows: acetone - 811°K (1000°F), amyl acetate - 672°K (750°F), aniline - 811°K (1000°F), butane - 703°K (806°F), phenol - 988°K (1319°F), toluene - 811°K (1000°F).

Compatibility problems, should they arise, could be addressed by judicious selection of PE resins available. Ultra-high-molecular-weight and cross-linked PE show advanced chemical stability. The former resin could be readily welded according to this work. But fabrication of receivers may be more difficult than that of receivers employed here. Of the latter resin, welding may be a more difficult operation.

Resins other than PE were employable to resolve incompatibility, but in our opinion chemically modified PE was the most cost effective selection for encapsulating drums. For addressing difficult compatibility problems, chlorinated PE was an excellent candidate.

In summary, welding and PE would be safe and suitable for encapsulating most 208-liter (55-gal) drums holding hazardous wastes. The exceptions to this generalization would yet be manageable. With care, welding can be carried out readily as a remote operation by automating the technique described here. Problems with compatibility could be solved by judicious resin selection.

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APPENDIX A

COMMERCIAL METHODS FOR MANAGING 208-LITER (55-GAL) DRUMS HOLDING HAZARDOUS WASTES

Recovery drums are used in commercial operations to manage failing hazardous waste containers--that is, they have been employed for repackaging leaking containers and for storing chemical processing plant by-products. Their use involves inserting a 208-liter (55-gal) container into the open-head recovery drum. The drums are then sealed with glues and/or gaskets and bolted hoops.

Recovery drums in greatest use are approximately 321-liter (85-gal) capacity, although drums from 246-liter (65-gal) to 416-liter (110-gal) capacity have been accepted for use in transporting defective or leaking packages.[9]

Since the recovery drums are made of steel, they are subject to the same corrosive forces as their 208-liter (55-gal) inserts. The drum walls are not homogeneous: The drums are sealed with gaskets, sealants, hoops, and threads.

The two types of recovery drums are shown in Figures 1-A and 2-A, and additional details describing them are listed in Tables 1-A through 4-A. Further information is available from Clearing Container, 6700 S. LeClaire, Chicago, Illinois 60638, and from Round Container Co., Inc., 15915 Laurel Rd., Chagrin Falls, Ohio 44022.

Figure 1-A. Coated steel open-head drum suitable as an overpack for leaking or damaged containers up to 24 in. in diameter and 36 in. high. (Available from Clearing Container, 6700 S. LeClaire, Chicago, Illinois 60638.)

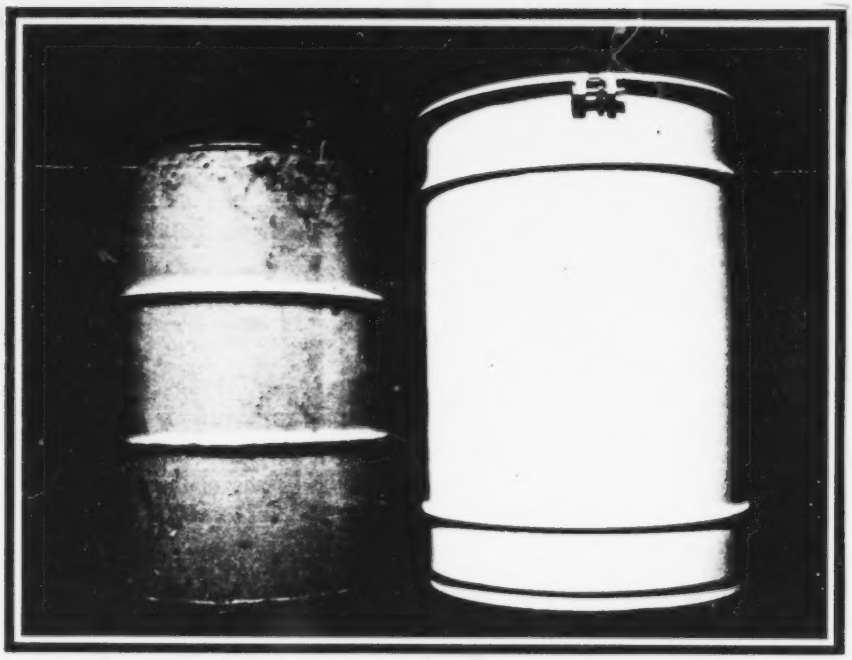


Figure 2-A. Round recovery drum. (Available from Round Container Co., Inc., 15915 Laurel Rd., Chagrin Falls, Ohio 44022.)

TABLE 1-A. SPECIFICATIONS FOR RECOVERY DRUM MODEL #200*

Parameter	Specification
Capacity:	85-gal (322 liters)
Dimensions:	26" x 38 5/8" (660 x 981 mm)
Tare weight:	78# (35.4 kg)
Interior ft^3:	11.2 (.317 m^3)
Ocean shipping cube:	16/5
Cover	16 ga. comm. grade carbon steel
Body	16 ga. comm. grade carbon steel
Bottom	16 ga. comm. grade carbon steel
Lock ring	12 ga. bolted drop forged 5/8" bolt & nut
Rolling hoops	3
Gasket	Contour formed rubber gasket
Lining	Epoxy phenolic type
Exterior paint	Yellow with black stripes
Packaging	Polyethylene-wrapped
Construction dcmensions:	
Overall height (overlock ring)	38 5/8" (981 mm)
Overall height (cover off)	38 3/8" (975 mm)
Chime depth (bottom)	3/4" (19 mm)
Inside height (between heads)	36 3/8" (924 mm)
Convexity (bottom)	3/8" (9.5 mm)
Overall diameter (over roll. hoops)	(26 7/8" (708 mm)
Inside diameter	26" (660 mm)
Height of rolling hoops	7/16" (11 mm)
Dispensing outlet (in cover)	2" x 3/4" (50 x 19 mm)

*Manufactured by Clearing Container Corp., Chicago, Illinois.

TABLE 2-A. PRICE LIST FOR COMPONENTS OF RECOVERY DRUM KIT*

Item	Amount (effective March 16, 1979)
(1) Plug wrench	$ 2.75
2" Rieke plastic gate valve	3.50
(1) Cover gasket	.75
(1 pr.) Plastic gloves	3.00
5/8" x 3 3/4" Hex. head bolt	.75
15/16" Open end x 15/16" box wrench	4.75
(1) Stainless steel self-tap sheet metal screw	.10
(1 pr.) Safety goggles	2.50
(1) Vinyl apron	1.75
Instruction pamphlet	N/C
Universal carrier for recovery drum (Portable and self-contained)	$60.00

*Manufactured by Clearing Container Corp., Chicago, Illinois.

TABLE 3-A. PRICE SCHEDULE FOR MODEL #200*

Item	Amount (effective March 16, 1979)
1-9	$95.00
10-24	85.00
25-49	75.00
50-99	70.00
Over 99	62.50

*F.O.B. shipping point, Clearing Container Corp., Chicago, Illinois.

TABLE 4-A. Round Recovery Drum Specifications

Item		Specifications
1.	GENERAL	This specification gives the minimum requirements for a full open-head steel drum of 83-gal approximate capacity.
2.	REQUIREMENTS	
	Material	Body and heads shall be 16-gauge (0.0533 Min.) steel.
	Dimensions	Inside dimension shall be 26.00 approx. and 36.50 in. inside height with cover on.
	Construction	Heads shall be flat with bottom chime reduced to 25.65 in. max. outside diameter to allow stacking. Rolling hoop location and the addition of a third hoop is optional.
	Closure	Drum shall be closed by a 12-gauge bolted ring with drop forged lugs, and a 5/8-in. bolt and nut. The bolt shall be 3 1/2 in. long and threaded to within 1/2 in. of the head.
	Gasket	A gasket adequate to prevent leakage shall be permanently attached to the top head (cover). Glue shall be of the non-hardening type.
	Finish	All interior and exterior surfaces shall be coated with a rust-inhibiting metal primer. Exterior surfaces shall be coated with a white enamel.
	Performance	Each drum closed as for use shall meet a leak test with an internal air pressure of 7 psi. Drum is to withstand a hydrostatic pressure test at 15 psi for 5 min.
	Packing	Good commercial packaging methods are used to assure damage-free delivery.
	Tar Wt.	80# approx.

APPENDIX B

ROTATIONAL MOLDING

INTRODUCTION

Rotational molding (also referred to as rotomolding and rotocasting) is a plastics processing technique utilized to manufacture a wide variety of products ranging in size from small technical components and toys to large agricultural tanks in excess of 22.7 m^3 (6000-gal) capacity (Figure 1-B). The application of rotomolded parts depends primarily on the selected polymer. For example, polyethylene is rotomolded into items such as holding tanks for corrosive chemicals.

Rotomolding provides several advantages when compared with other molding techniques: 1) Costs for molds and tooling are less; 2) prototype steel molds can be fabricated for experimental purposes without great expense; 3) it does not usually require secondary tooling during processing; 4) there is very little scrap; 5) relatively stress-free items are produced since molten resin is not displaced and cooled, thus protecting against environmental stress cracking; 6) changing wall thickness of end products is achieved without equipment modification; 7) high production output techniques such as the racetrack concept (a continuous molding track anticipated to deliver a rotomolded drum every 30 sec) are being commercialized.[10]

METHODS

There are two general categories in rotomolding--biaxial rotation, and rock 'n' roll.

Biaxial Rotomolding

In this technique, the powdered polymer is loaded into an enclosed, thin shell type of mold. The mold is rotated about two perpendicular axes during heating and cooling cycles which allows the resin to melt and fuse to the mold surface, respectively. The machinery has three basic elements: the rotating spindle, heating chamber, and cooling chamber. The spindle transmits basic rotation to the mounted molds where the rotation is mechanically converted into a second, simultaneous rotation about a perpendicular axis. Heating is typically accomplished in hot air ovens and cooling is supplied by water mist. A schematic of this technique is provided in Figure 2-B. Figure 3-B shows a three-spindle machine whereby parts are continuously processed through a loading, heating, cooling and unloading cycle.

Figure 1-B. Rotomolded polyethylene tanks.

Rock 'n' Roll

In this process the powdered polymer is loaded into the mold during heating. The mold is open on one end only. Rotation occurs about one axis, while simultaneously rocking or oscillating along a perpendicular plane during heating and cooling cycles. Machinery consists of a rotation assembly and burner. Typically, the mold is mounted on arms which impart rotation along a horizontal axis. Below the mounted mold is an open flame (gas) burner unit extending the length of the mold. The burner and mold are mounted such that simultaneous rotation and oscillation occurs. Cooling can be accomplished within a water spray chamber, or naturally in air. A sketch of this process is shown in Figure 4-B.

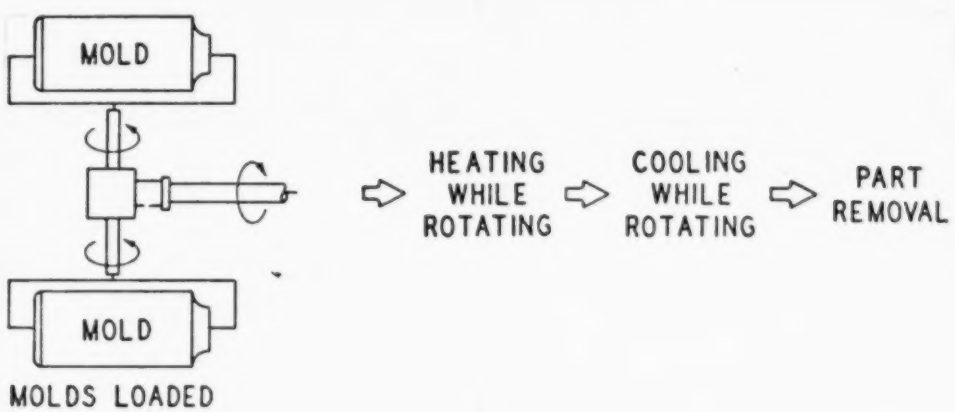


Figure 2-B. Schematic of biaxial rotational molding process.

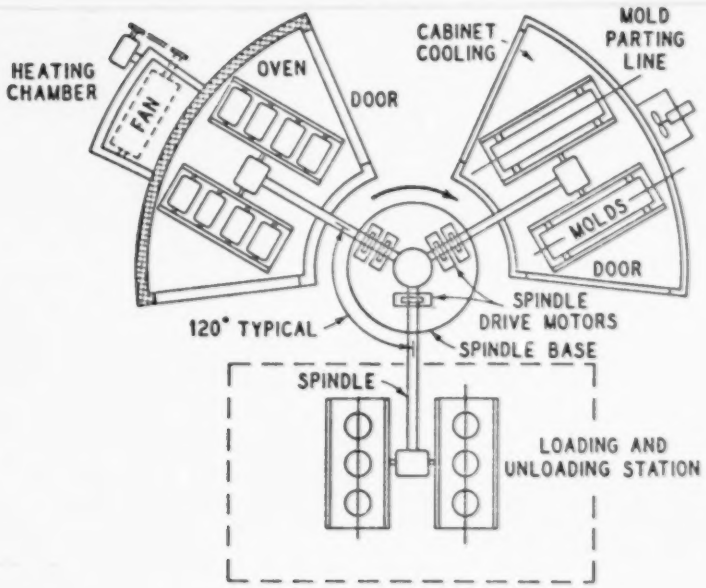


Figure 3-B. Three-spindle indexing machine.

ROTOMOLDED CONTAINERS FOR ENCAPSULATION

Surveys of the rotomolding industry in the greater Los Angeles area were carried out to generate data regarding materials needed for encapsulation. It was found that the large open-head containers used in this work are common items of commerce and their position in the market place is growing. However, these containers are generally not of the optimum dimensions for encapsulation (Figure 5-B). Several custom roto-molders were contacted and provided information for fabricating prototypes to exact specifications (Table 1-B). In addition, economy of scale would result in materials savings as described in Section 8.

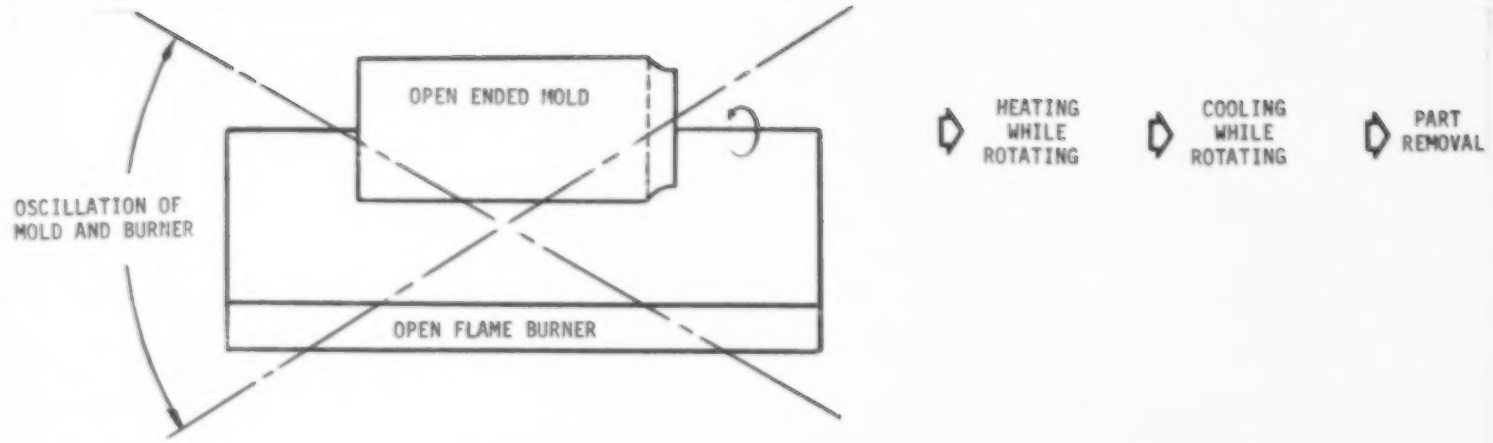


Figure 4-B. Rock 'n' roll rotomolding process schematic.

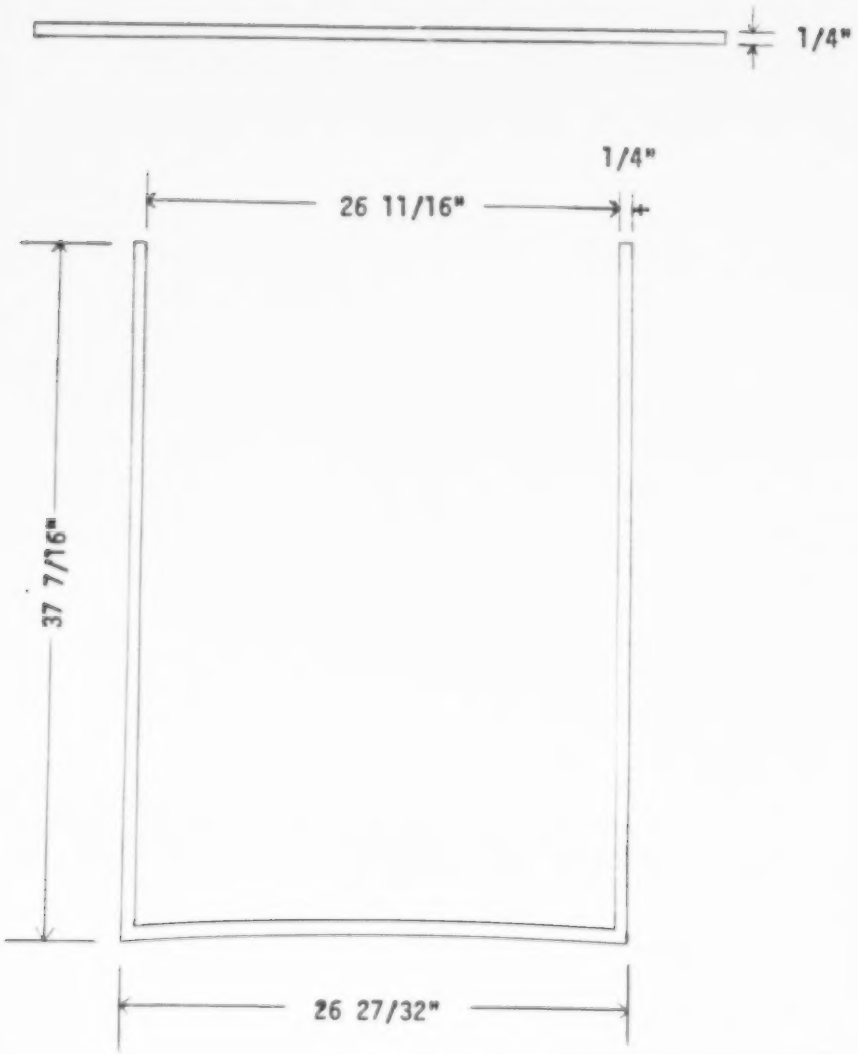


Figure 5-B. Optimum dimensions of materials specified for encapsulation.

TABLE 1-B. SURVEY OF ROTOMOLDERS* OF 321-LITER (85-GAL) CONTAINERS FOR ENCAPSULATION

Company	Company Size	Molding Method/ Equipment	Molding Tolerances	Estimated Cycle Time	Cost (1978 $)	Production Rate	Mold Cost	Mold Materials
Holloform (Woodland Hills, Ca)	Large	"Biaxial"	-	45-50 min	$3.85/kg ($1.75/lb)	10/day	$1500-3000	Stainless steel or aluminum
Formatron (Burbank, Ca)	Small	"Rock-'n'-Roll"	±0.0625 cm (± 1/16 in)	45 min	$4.62-$4.93/kg ($2.1 -$2.24/lb)	10-50 total	$500	Protype steel
Lee-Meyers Plastics (Westminster, Ca)	Small	"Biaxial"	-	30-35 min	$2.31/kg ($1.05/lb)	0-150 total	$50C-6000	Aluminum
Rotational Molding, Inc. (Gardena, Ca)	Medium	"Biaxial"	±0.0625 cm (± 1/16 in)	~ 60 min	$3.08/kg ($1.4 /lb)	-	$2000	Stainless steel

* Rotomolders were surveyed in the greater Los Angeles area.

APPENDIX C

ANALOGOUS ART: PLASTICS WELDING

Plastic welding has been used commercially for joining PE pipe.[11, 12] This art has been employed in the United States and Europe for about 25 years. Literature studies of pipe welding were conducted to compile data to serve as a guide for encapsulation of 208-liter (55-gal) drums with PE pieces. Table 1-C lists the welding conditions required to optimize the weld joining of PE pipe. In addition, Table 2-C lists conditions required to weld different grades of PE pipe. Table 3-C lists the properties of plastics from which the pipes listed in Tables 1-C and 2-C were fabricated and gives properties of materials selected for encapsulation. This information served as a basis for initial encapsulation studies.

The remaining portion of this appendix provides information about pipe welding methods, materials and equipment.

PIPE WELDING

Butt fusion is the technique for joining ultra-high-molecular-weight, high-density polyethylene (UHMWHDPE) pipe. It has been an accepted pipe joining procedure in the gas and municipal services industries in the United States since 1962. The technique is used in many industrial applications (e.g., pumping chemical and sewage effluents from processing plants, dredging in ocean operations, and piping applications under arctic conditions).

The principle in any type of heat fusion is to heat the two surfaces to a fusion temperature, then make contact between the two surfaces and allow the two surfaces to fuse together under pressure, if necessary. On cooling, the original interfaces are gone, and the two parts are united. Figure 1-C shows a cross-sectional view of a butt-fused pipe.

HEAT FUSION JOINTS

Heat fusion joints are made by heating mating surfaces to their fusion temperature and then bringing the surfaces into contact with one another. ASTM D2657 is a recommended practice for heat joining of thermoplastic pipe and fittings. When properly made, heat fusion joints should be as strong as or stronger than the pipe itself.[3,13] Direct application of heat using a torch or other open flame is prohibited.

It should be noted that cold weather and wind can adversely affect the heat fusion process. Such items as shielding, higher temperatures,

TABLE 1-C. OPTIMUM FUSION CONDITIONS FOR COMMERCIAL PE PIPES

Trade Name	Surface Temperature of Heater Plate	Pressure on* Heater Plate, MPa (psi)	Heating Time, Min.	Bead Thickness,** mm (in.)	CHANGE-OVER*** Time, Sec.	Fusion Pressure MPa (psi)	Duration of Fusion Pressure	Vendor/Source of Specification
Hostalen GUR	473-493°K (392-428°F)			8 (0.32)		0.98-1.96 (142-284)	Until cool to touch	Mr. Prought of Hoechst Plastics; Farbwerke Hoechst AG Brochure 1777, P. 27
Hostalen GM5305	473°K (392°F)					0.14-0.19 (21-28)	Until cool to touch	Hoechst Plastics, Farbwerke AG, Brochure 1777, P. 33
Monoline Pipe	471°K (392°F)	0.06 (9)	1-3 min. after bead forms			0.14-0.27 (28-56)	Until cool to touch	Mr. T. Braman of Joseph T. Ryerson & Son, Inc.; Bulletin AK-10-236, pp. 23-27
Driscopipe 7600	519-533°K (475-500°F)			3.18-4.78 (0.125-0.188)	6-10	1.03 (150)	Solidify until cool to touch, ~10 min.	Phillips Chem. Co. Butt Fusion Brochure, M.D. Weller of I.A. Piping Systems, Inc., Mr. B. Pobbins of Mansell & Robbins, Inc
Plastrooga PI	508°K (455°F)	0.02 (2.9)	~4	1 (0.04)	3	0.1 (14.5)	3 min.	Barber and Atkinson, Journal of Material Sciences, , pp. 1456-1461
Aldyl "A" PI	443°K (330°F)	0.02 (2.9)	~4	1 (0.04)	3	0.1 (14.5)	3 min	IBID

* Pressure required to insure complete surface contact of Heater Plate with pipe ends
** Molten polymer displaced from heater plate-pipe interface to inner/outer circumferential surface of pipe
*** Maximum time lag between heater plate removal and joining pipe ends.

TABLE 2-C. PIPE WELDING OF DRISCOPIPE 7600 FLANGE TO APACHE HDPE PIPE*

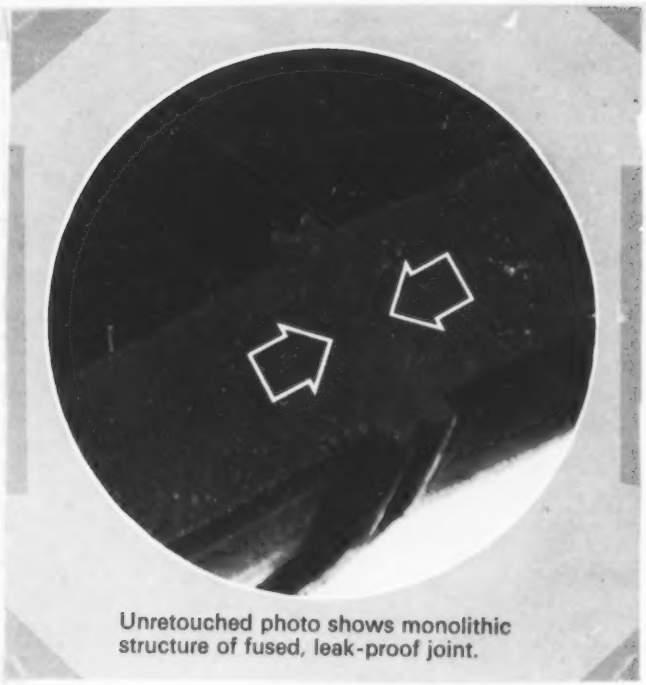
Welding Parameters	English Units	SI Units
Heater Temperature	500°F	533°K
Change-over Time	4-6 sec	5-6 sec
Pressure on Heater Plate to Melt Pipe Ends	200 psig	1.38 MPa
Fusion Pressure	200 psig	1.38 MPa
Duration of Fusion Pressure	25-30 sec	20-30 sec
Bead Thickness		
Driscopipe Flange	1/16 in.	1.59 mm
Apache Pipe	1/4 in.	6.35 mm

* Welding different grades of PE is a technique employed for joining pipes specified for ocean dredging applications (Dredgemaster, City of Long Beach, California).

TABLE 3-C. PROPERTIES OF PLASTICS EMPLOYED FOR COMMERCIAL PIPES AND ENCAPSULATION

Trade Name	Pipe Outside Diameter, mm (in)	Thickness, mm (in)	Melt Flow g/ 10 min.	Density, g/cm^3	Softening/Melting Range °K (°F)
Hostalen GUR	——	> 30 (> 1.8)	> 0.1	0.94	408-411 (275-280)
Hostalen GM5105	< 1200 (< 47.2)	(≤ 37.1) (≤ 1.46)	0.3	0.955	400-404 (261-269)
Monoline Pipe	406-1220 (16-48)	12.4-41.3 (0.488-1.626)	0.3	0.955	400-404 (261-269)
Driscopipe 7600	152-1220 (6-48)	5.18-36.9 (0.204-1.454)	1.5	0.955	398 (257)
Plastronga PE	60.1-60.6 (2.37-2.39)	6.6-7.3 (0.26-0.29)	0.05	0.957	398 (257)
Aldyl "A" PE	60.2 (2.37)	5.8 (0.23)	1.9	0.939	388 (239)
Marlex HDPE*	~711 * * (~28 in)	~6.4 * * (~0.25 in)	6.9	0.955	383-388 (230-239)

* Material Selected for Encapsulation
** Encapsulates dimensions



Unretouched photo shows monolithic structure of fused, leak-proof joint.

Figure 1-C. Cross section of welded pipe wall.

and longer heating times must be considered under these conditions.

FUSION PROCEDURE

Butt fusion procedures are simply and easily performed. The procedure recommended for Driscopipe 7600[3] UHMWHDPE has been reduced to seven steps (Figure 2-C):

1. Wipe each pipe end clean inside and outside to remove dirt, water, grease and other foreign material.
2. Square the end of each pipe section to be fused using the facing tool of the fusion machine or plastic pipe cutters. Remove cuttings and burrs from pipe ends.
3. Check line-up in fusion machine to see that the pipe ends meet squarely and completely over the entire surface to be fused. Proper alignment is necessary to obtain uniform heating of pipe ends and uniform bead at the fused joint.

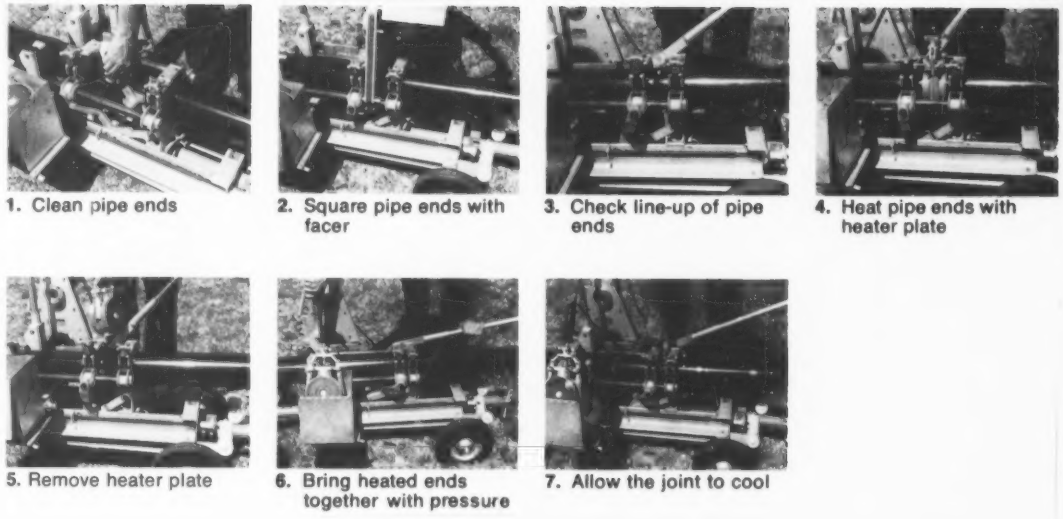

1. Clean pipe ends
2. Square pipe ends with facer
3. Check line-up of pipe ends
4. Heat pipe ends with heater plate
5. Remove heater plate
6. Bring heated ends together with pressure
7. Allow the joint to cool

Figure 2-C. Pipe-welding procedure.

4. Insert the heater plate between the aligned pipe ends. Bring and hold the pipe ends in contact with the heater plate. Maintain contact and allow pipe to heat soften about 1.59 to 4.76 mm (1/16 to 3/16 in.) back from the pipe, depending on size. Soften approximately 1.59 mm (1/16-in.) on all sizes up to 76.2 mm (3 in). On 76.2 to 152 mm (3 to 6 in.), soften to 4.76 mm (3/16 in.). Softening can be judged by the appearance of the pipe end as the material softens.

5. Carefully move the pipe ends away from the heater plate and remove the plate.* If the softened material sticks to the heater plate, discontinue the joint. Clean the heater plate, resquare pipe ends and start over.

6. Bring the heated pipe ends together with a firm pressure to form a uniform upset flash around the entire circumference of the pipe about 3.18 to 4.76 mm (1/18 to 3/16 in.) wide. The bead will have the appearance of a double upset flash. Pressure is necessary to cause the heated material to flow together, thus giving a fusion bead that is distinctive in appearance to this type of material.

7. Allow the joint to cool and solidify until the bead feels hard, then remove from the line-up clamps. Inspect the joint for a uniform nonporous appearance. A joint can have proper appearance even if made at too high a temperature of the heating plate. If the joint appears faulty, simply cut the joint out and repeat procedure.

BUTT FUSION JOINT STRENGTH

There are several ways in which the strength of a butt fusion joint can be illustrated. These are by impact, burst strength, tensile pull and flattening.

A test that can be performed to indicate the integrity of a butt fusion joint is Tup Impact, ASTM D2444, with the free falling tup hitting the specimen at the joint. This, although more severe than normally encountered in field installations, does serve to show the outstanding impact resistance in the joint areas. The butt-fused specimen pictured was placed under the tup and impacted (Figure 3-C).

A tensile pull test on a specimen with a butt fusion joint will illustrate the strength in the longitudinal direction. Figure 4-C shows the result of a typical tensile pull with the elongation and illustrates that the two pieces have become one but that the joint is stronger than the pipe itself.

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* It was stressed that the change-over time (the time from the removal of the heater to the pressing together of the pipe ends) must be as brief as possible--no more than 10 sec. A longer change-over time results in skinning (this is, the formation of a thin layer of solid polyethylene that prevents optimum fusion of the two pieces of molten polyethylene).

Another test of a practical nature may be performed in the field to demonstrate the strength of butt-fused joints. A joint is placed beneath the track of a back-hoe or similar implement and mashed flat. The pipe is not shattered or destroyed, but will return to near normal roundness in a few minutes and can be used normally for years (Figure 5-C).

PIPE-WELDING EQUIPMENT

This appendix presents a description of the commercially available polyethylene pipe-welding equipment. The leading manufacturer of complete butt-welding units in the United States is McElroy Manufacturing, Inc., Tulsa, Oklahoma. There are eight fusion units marketed by McElroy; they differ in the diameter pipe which they weld. Pipe in diameter from 1.27 to 122 cm (0.5 to 48 in.) can be welded using McElroy equipment. The fusion units are functionally similar to each other and each unit contains the following components:

1. Clamping units to align pipe ends.
2. Hydraulic system to provide fusion pressure.
3. Facer to square the pipe ends.
4. Heater to melt pipe ends.

The manner in which the components are manipulated depends on the model size. For example, in the smaller welding units the facer is hand-powered, whereas in the larger units it is hydraulically powered. Similarly, in the smaller units the heater and facer are hand positioned, whereas in the larger units hydraulics are used to position the components.

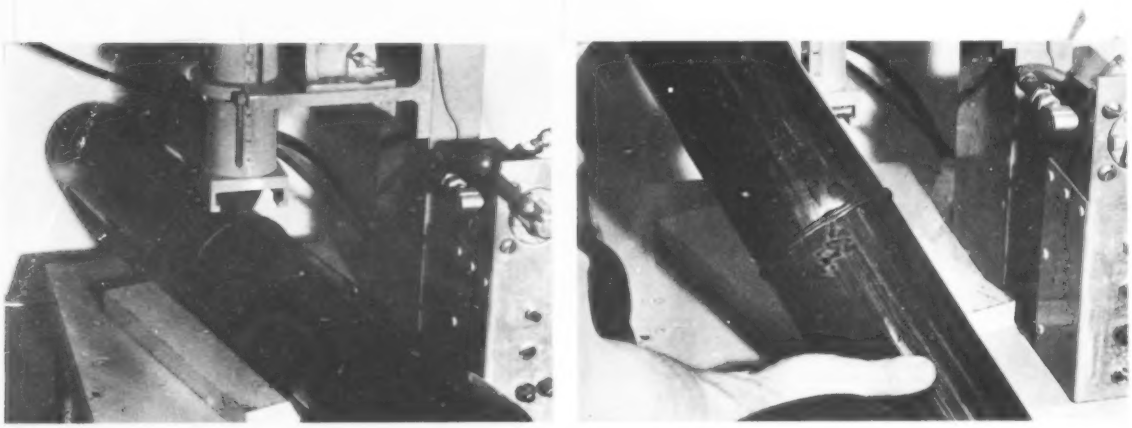


Figure 3-C. Tup impact test.

Figure 4-C. A welded joint after elongation.

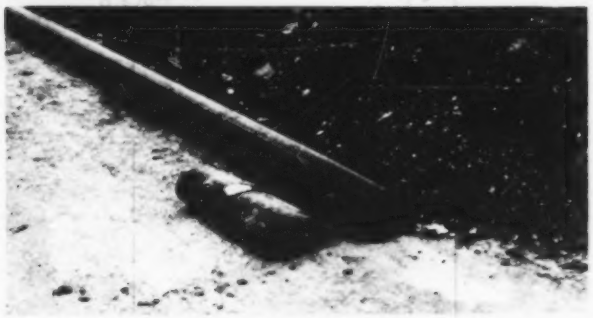
The McElroy No. 36 Fusion Unit fuses 30.5-cm through 91.4-cm (12-in. through 36-in.) pipe and is of sufficient size to handle 321-liter (85-gal) polyethylene receivers. However, because the weight of 91.4-cm (36-in.) pipe segments 12.2-m (40-ft) long is much greater than the weight of a 321-liter (85-gal) receiver, the pipe fusion unit is much larger than the encapsulation apparatus. The McElroy No. 36 Fusion Unit is 419 cm (165 in.) long, 166.4 cm (65 1/2 in.) high, and 171.5 cm (67 1/2 in.) wide. The unit weighs 2045 kg (4500 lb) and is mounted on a trailer. The hydraulic system of the McElroy unit is more complex than the hydraulic system of the encapsulation unit. All movable functions of the Model No. 36 Fusion Unit are powered hydraulically. Hydraulics are used to open and close the jaws of the clamps, provide the fusion force, power and position the facer, and position the heater and pipe lifts. To actuate the hydraulic cylinders, a 15-gpm, 6.0-MPa (875-psi) pressure compensating van pump is used. This pump is powered by a 7.46 kW (10 hp), three-phase, 60-Hz, 230-V motor. By comparison, the pump used in the encapsulation apparatus is rated at three gpm and is powered by a 1.12-kW (1-1/2-hp) motor.

The heater used in the pipe fusion equipment is larger than the heater used in the encapsulation apparatus. Because the major heat load involves bringing the heater from ambient to melt temperature (in extreme meteorological conditions, heat loss to the atmosphere becomes appreciable), the McElroy heater is rated at approximately three times the encapsulation apparatus heater (14.8 kW versus 5.5 kW).

Finally, the price of the McElroy butt fusion machine is approximately $70,000, whereas the prototype encapsulation apparatus was built for approximately $2,500. The butt fusion unit is further described in a technical bulletin available from McElroy Manufacturing, Inc., 833 N. Fulton St., Tulsa, Oklahoma 74112.

BACK-HOE PREPARING TO CRUSH A DRISCOPIPE BUTT FUSED JOINT

THE JOINT IS MASHED FLAT



REMOVE THE BACK-HOE AND INSPECT THE PIPE AND JOINT

THE JOINT IS IN EXCELLENT CONDITION AND THE PIPE ALMOST FULLY RECOVERS IN A FEW MINUTES

Figure 5-C. Joint performance under simulated field conditions.

APPENDIX D

ALTERNATIVE FRAME DESIGN

The steel H-frame used in the prototype apparatus was heavier duty than that needed to support the welding pressures generated during encapsulate fabrication. (Commercially available H-frames which were lighter duty had bed diameters too narrow to accommodate PE receptacles.) However, for field operations, a custom-fabricated steel or aluminum frame would be lighter in weight, less expensive, and field erectable.

The major design criterion for a custom frame is the spacing between the posts. To facilitate positioning and removal of the PE receivers from the frame, the posts were positioned 88.9 cm (35 in.) apart. To provide planer support for the hydraulic cylinder, three posts are provided in an equilateral triangular arrangement. The posts can be threaded into a triangular base plate and over-head plate. The heater holder could be attached to any of the posts. As a first approximation, it was estimated that the poles should be about 2.54 cm (1 in.) in diameter and the support plates were 0.635 to 1.27 cm (1/4 to 1/2 in.) thick (Figure 1-D).

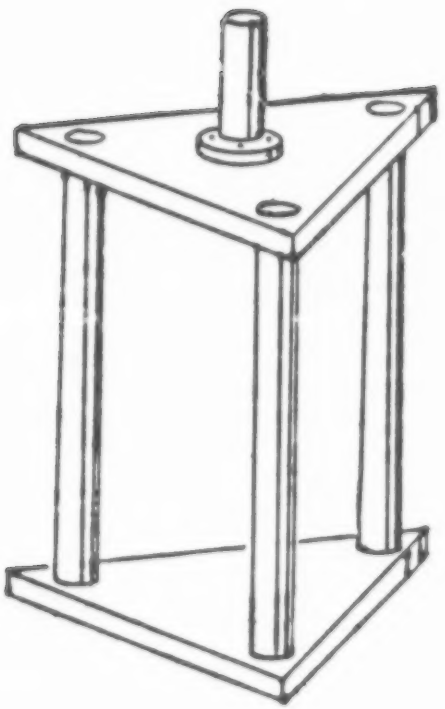


Figure 1-D. Alternative press frame design.

APPENDIX E

IMPROVED HYDRAULIC CIRCUIT

Two people are required to operate the prototype apparatus used in the proof-of-principle testing of the plastic welding process. One person operates the heater using the heater holder while the other person operates the hydraulic system using the Four-way valve's remote controller. A production-scale operation would seek to minimize the labor involved in drum management. There are potentials for automating the encapsulation operation by modifying the hydraulic system.

The availability of THK Robot hydraulic cylinders,* which provide rectilinear and rotational motion, would allow the heater to be manipulated hydraulically. Consequently, all the motions required for the welding step can be actuated hydraulically. The sequence of motions can be controlled by several different types of fluid logic circuits.

One type of circuit would be similar to the circuit employed in the prototype apparatus. It would use pneumatically actuated ball valves (replacing the manually employed ball valves in the prototype) and a THK Robot cylinder as the primary output for controlling the heater movement. A timing device or position/pressure sensors could be used to control the pneumatic circuit allowing different valves to be opened and shut sequentially. For example, a timing device such as a Program-Air+ programmable air logic could be used to achieve the desired sequence of events.

An example of such a circuit is presented:

Two hydraulic cylinders are utilized: (1) a two-way cylinder to provide rectilinear motion to the cover and fusion pressure, and (2) a THK rectilinear/rotational cylinder to control the heater's positioning. The circuit utilizes eight pneumatically actuated ball valves, two pressure relief valves, and a pneumatically actuated four-way spool valve. The sequential program for encapsulate fabrication would be as follows:

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*Cylinders and further information are available from THK Co. Ltd., 13-38, 2-Chome, Kamiosaki Shinagawa-ku, Tokyo 141, Japan.

+Program-Air and further information are available from DYNAMCO Inc., 2639 Manana Drive, Dallas, Texas 75220.

Programmed Steps	Valve Positions	
1. Lower the platen to the heater. Apply kiss pressure for 2 minutes.	B-D-G	Open
2. Lower both platen and heater to receiver rim. Apply kiss pressure for 1 minute.	B-D-G-E-H	Open
3. Relieve kiss pressure for 1 minute.	A	Open
4. Switch spool valve.		
5. Raise the platen.	B-E-H-A	Closed
6. Raise the heater.	G-D	Open
7. Switch spool valve.	E-H	Open
8. Rotate heater.	F-H	Open
9. Lower heater and apply fusion pressure.	E-F-H	Closed
Return spool valve.	B-D-G	Open

Utilizing this circuit (Figure 1-E), an operator only needs to activate the program to achieve the fusion necessary for encapsulate fabrication. Program activation could be achieved from a remote location.

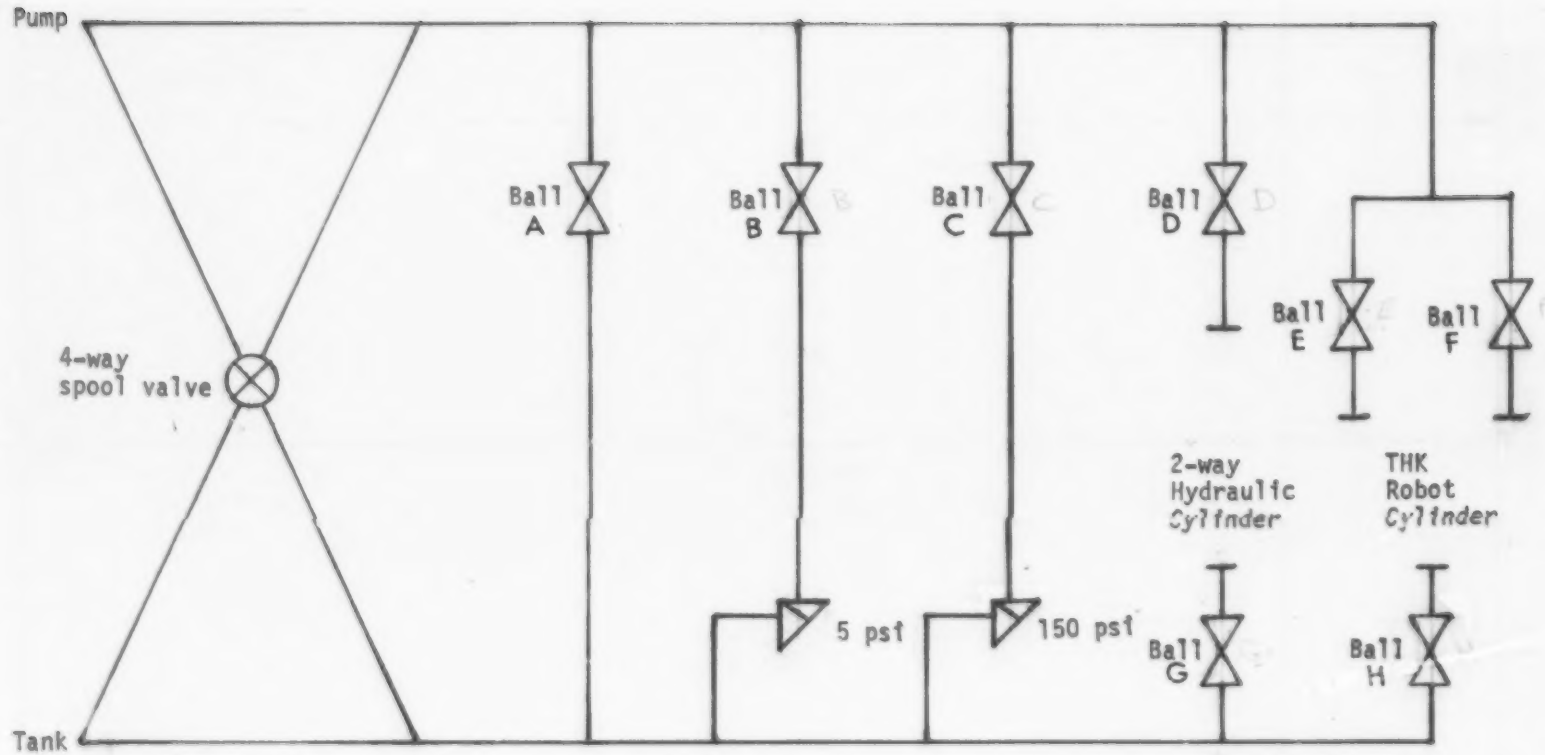

Figure 1-E. Pneumatically actuated hydraulic circuit for automated encapsulate fabrication.

APPENDIX F

OTHER HEATER DESIGNS

The selection of a heater suitable for plastic welding work was given special attention since they were known to be the most performance sensitive components on commercial pipe-welding machines. Field surveys and engineering design sessions were carried out to generate applicable heater designs. For use with the prototype apparatus described in Section 4, a cast aluminum heater was selected. However, optional designs were investigated and are discussed herein. The most attractive feature of each of these designs is that the heating elements are replaceable. Thus upon extended field use, heating elements within the heater could be replaced. (This is in contrast to custom cast-in heating elements that cannot be replaced upon failure and result in discarding expensive custom equipment.)

Sandwich Heater Design

A schematic of the basic design of a sandwich heater is given in Figure 1-F. It is similar in configuration and specifications to the cast aluminum heater described in Section 4. The heater consists of upper and lower heating plates which are machine grooved to accommodate a tubular heating element. The heater is assembled with bolts which allows servicing or replacement of inefficient tubular elements without discarding heater plates. Each tubular heating element costs approximately $95.00.

Cartridge Heater Design

A schematic of a cartridge heater design is given in Figure 2-F. Its configuration and specifications are similar to those described in Section 4. The heater consists of a single ring plate with holes drilled radially around the ring. Cartridge heating elements are mounted in each hole. Heater circuitry can be monitored, thus allowing replacement of individual cartridges. Cartridges cost approximately $4/unit.

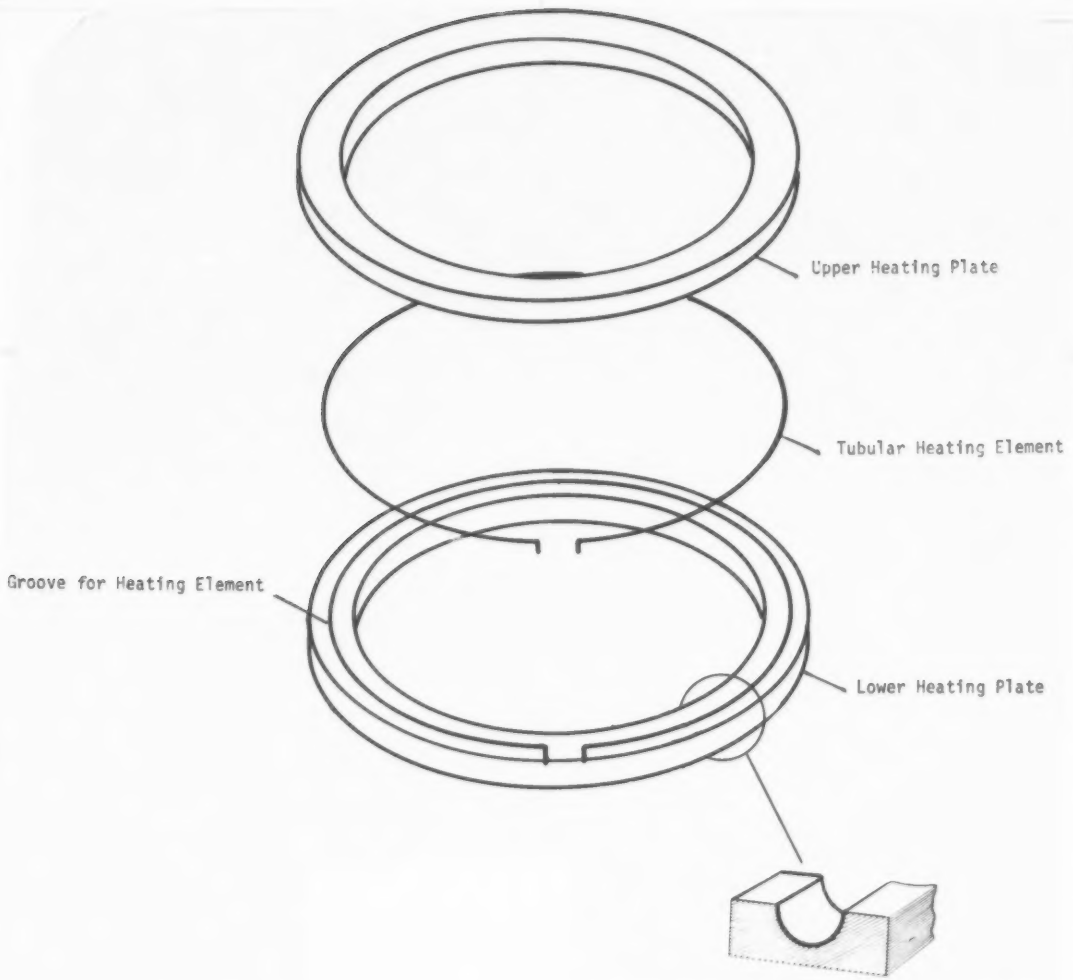

Figure 1-F. Exploded view of sandwich heater design.

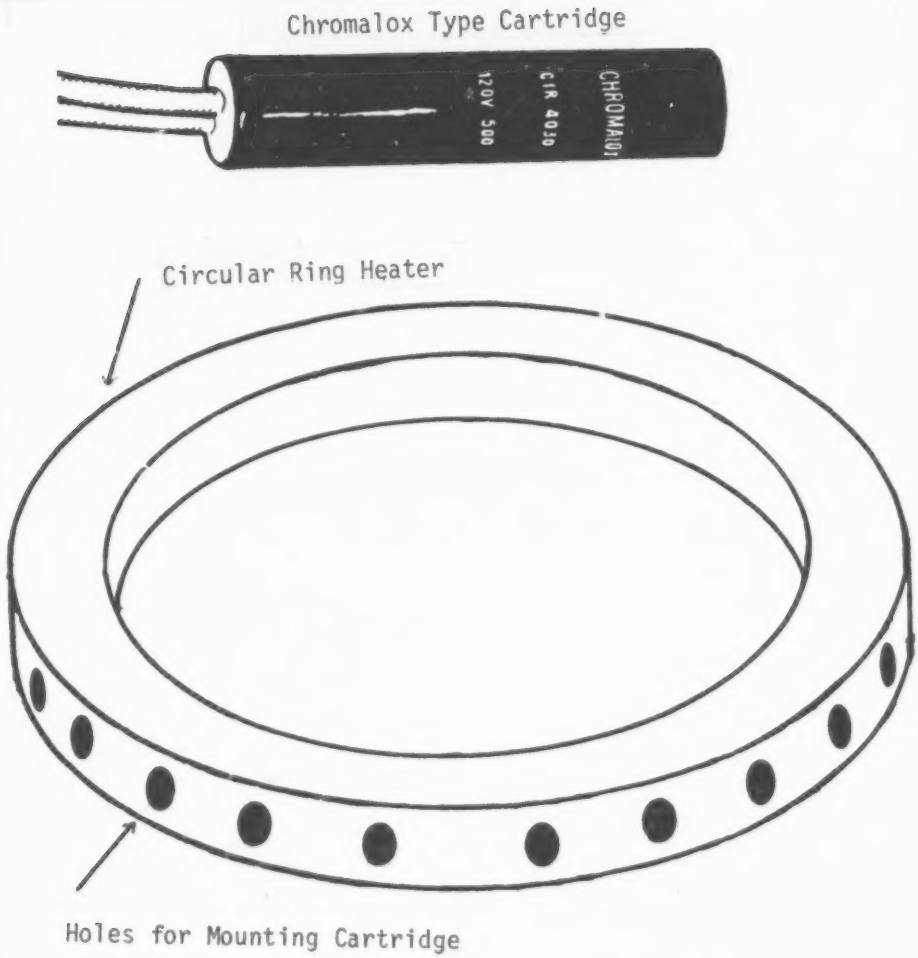

Figure 2-F. Cartridge heater design.

APPENDIX G

ULTRASONIC JOINT INSPECTION CONCEPT

A method employed by the commercial pipe welding industry for inspection of welded piping systems is a suitable nondestructive test for showing the fabrication of effective welded encapsulates. This method uses ultrasonic waves to detect flaws or imperfections in welded plastic pipe joints. The technique is fast and accurate. Inspection of welded pipes by ultrasonics is recommended by the American Gas Association[14] and has been proposed for adoption by the American Society for Testing and Materials (ASTM Standards).